Appendix D

Appendix E

City of Boston
Town of Brookline

Phase 1 Muddy River Flood Control, Water Quality and Habitat Enhancement, and Historic Preservation Project

Volume 4

Appendix D **Wildlife Habitat Evaluation and Vegetation Assessment**

Appendix E **Additional Muddy River Hydraulic Analysis**

December 2001

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In Association with:

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Appendices

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WILDLIFE HABITAT EVALUATION AND VEGETATION ASSESSMENT

December 13, 2000

Express Mail

Bruce Conklin
Camp Dresser & McKee, Inc.
One Cambridge Street
50 Hampshire Street
Cambridge, Massachusetts 02139

Re: Wildlife Habitat Evaluation
Emerald Necklace
Boston, Massachusetts

[LEC File: CDM/9213.01]

Dear Mr. Conklin:

LEC Environmental Consultants, Inc. (LEC) is pleased to provide you with the following report detailing our findings of current habitat conditions and species utilization along the Emerald Necklace in Boston, Massachusetts. The habitat evaluation was conducted in accordance with the *Massachusetts Wetlands Protection Act* Regulations (310 CMR 10.54 (4) (a) and 10.60) and DEP's Wetland Program Policy Guidelines (DEP Wetlands Program Policy 88-1 and Wetlands Wildlife Advisory #2, 1988), as well as floral and faunal inventory. The study site comprised the three primary links of the Emerald Necklace; Olmsted Park, the Riverway and Back Bay Fens.

LEC conducted a baseline survey of species, i.e. avian, mammals, aquatic and terrestrial invertebrates/vertebrates, fish, amphibians, and reptiles, to ascertain population diversity and densities. In addition, LEC mapped vegetation cover types and noted habitat potential throughout the study site. Given the limited temporal scale of this particular study, projecting habitat potential through established vegetative communities is an effective methodology from which to infer species utilization.

The Emerald Necklace is an intensely utilized urban park affording the city resident access to the watercourse as well as continuous green space for human and domestic animal recreation. Given the intense development surrounding the park system, the Emerald Necklace is proof positive of the resiliency of nature. However, decades of neglect have left their scar on the area, the most visible of which is a 5-acre stand of common reed *(Phragmites australis)* constricting the flow through the Back Bay Fens, as well as reducing the diversity of species utilization of this area. Other exotics are present in abundance throughout the Emerald Necklace, both floral and faunal; Canadian geese, Japanese knotweed *(Polygonum cuspidatum)*, Yellow-flag iris *(Iris pseudacorus)*, English sparrows, Glossy buckthorn *(Rhamnus frangula)* and European buckthorn *(Rhamnus cathartica)*, to name but a few. As aggressive exotic monocultures invade this or any ecosystem, diversity of species utilization will decline. The decline in the diversity of species utilization is due to a lack of structural heterogeneity, or variability in height and width of vegetation, of an ecosystem, and either the inability to adapt or intensive energy requirements of adaptation to introduced vegetation. Accordingly, to preserve or enhance diversity of species utilization, one must take a "bottom-up" approach, specifically by establishing a diversity of vegetative species throughout the ecosystem, which will in turn presume species diversity and utilization.

The following report documents the existing conditions of wildlife habitat throughout the three primary links of the Emerald Necklace. LEC has included the baseline data of species observed throughout the study period. Potential species utilization has been extrapolated from existing vegetation cover types. Vegetation management techniques and restoration suggestions for each of the three segments of the Necklace are proposed. The landscape of the Emerald Necklace transitions from a more natural system (Olmsted Park) to a man-made environment (Riverway, Back Bay Fens) as one moves downstream. The following report describes the links of the Emerald Necklace in that fashion, from the natural to the sculpted landscape.

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Thank you for the opportunity to provide these services. Should you have any questions or require additional information, please do not hesitate to call LEC (508) 759-0050.

Sincerely,

LEC Environmental Consultants, Inc.

Paul R. Lelito

Paul R. Lelito	Megan Raymond
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mbr: projects\9000\9213\WHE.doc

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Species Observations

1. Introduction

The following report documents the findings of a wildlife habitat evaluation of the Emerald Necklace in Boston, Massachusetts. The wildlife habitat evaluation was performed by LEC Environmental Consultants, Inc, (LEC) as part of the Muddy River restoration project sponsored by the City of Boston Parks and Recreation Department. The habitat evaluation was conducted in accordance with the *Massachusetts Wetlands Protection Act* Regulations (310 CMR 10.54 (4) (a) and 10.60) and DEP's Wetland Program Policy Guidelines (DEP Wetlands Program Policy 88-1 and Wetlands Wildlife Advisory #2, 1988). This report describes existing habitat conditions and species utilization throughout the three primary links of the Emerald Necklace (Olmsted Park, the Riverway, and Back Bay Fens). Given the limited temporal scale of this habitat evaluation, species utilization was inferred through established vegetation cover types in addition to direct observations. Vegetation management techniques and restoration strategies for the entire Emerald Necklace ecosystem are proposed.

2. Study Site

The Muddy River originates at the outlet of Jamaica Pond and flows 3.5 miles in a northeasterly direction to its confluence with the Charles River. The watershed is 5.6 mi^2 in area, and limited gravity driven pressure gradient; over the course of the 3.5-mile length of the Muddy River, the river drops 58-feet. However, a 57-foot drop is incurred within the first 100 feet of the river between the outlet of Jamaica Pond and the inlet to Wards Pond. The gradient over the remaining 3-miles is minimal to non-existent.

The site has changed significantly since Fredrick Law Olmsted first designed and implemented the park for the City of Boston in the late 19th century. The watercourse at that time was tidally driven. While the park is highly degraded in areas, with dense colonies exotic vegetation and active erosion, the overall palette for restoration is clean, as the 3.5 miles of contiguous open space is largely intact.

3. Methodology

LEC traversed each habitat type in its entirety and the surrounding periphery on foot. Data were collected on the vegetative communities and landforms, with emphasis given to wildlife habitat value. Identification of vegetation included assessing the structural heterogeneity of the plant communities, i.e. the canopy, shrub, and groundcover layers, with special consideration given to the presence of snags, cavities, burrows, basking sites, and other outstanding features. Actively eroding areas and intensively disturbed areas were noted. The Emerald Necklace ecosystem was assessed according to habitat cover type, including forested upland, manicured landscaping, riparian shrub and emergent wetland vegetation. Habitat value was assessed using the above criteria, creating the framework for this report.

Adjacent to the watercourse, the abundance and diversity of all animals observed (by sight and/or sound) during the assessment were recorded along with any other evidence of habitat use including tracks, scat, feathers, bone fragments, and browse marks. Wind speed, temperature, cloud cover, wildlife vocalization, and general habitat structure and composition were noted. LEC utilized a Coffelt Manufacturing Mark-10 electroshocking apparatus and a 20' by 5' seine to sample the aquatic environment. The aquatic environment was sampled extensively throughout the Back Bay Fens and Olmsted Park; however the nature of the sediments (i.e. soft) within the Riverway proper

precluded aquatic biota sampling. Temporarily stunned by the electroshock apparatus, fish were identified, measured and returned to the aquatic environment with no mortality.

4. Existing Conditions

The following sections document existing conditions of wildlife habitat of the Emerald Necklace. Wildlife species observed throughout the survey are listed in Appendix B, Species observations. General habitat structure, composition and potential are discussed below.

4.1 Olmsted Park

Olmsted Park is comprised of Wards Pond, Spring Pond, the Babbling brook, Willow Pond, and Leverett Pond, in addition to a bordering vegetated wetland (BVW) area that feeds Spring Pond through surface flow. Spring Pond was created by Fredrick Law Olmsted as one of three proposed Natural History Pools. Currently, this area may be considered one of the more desirable areas for wildlife along the Emerald Necklace, specifically because of the diversity of habitats present and the isolated and protected nature of the BVW feeding Spring Pond. In contrast to the majority of the Emerald Necklace, minimal manicured lawn exists in Olmsted Park and the landscape is more natural and self-sustaining.

The Massachusetts Division of Fisheries and Wildlife Natural Heritage Endangered Species Program maps Olmsted Park to contain two species of rare wildlife (Boston South quadrangle, WH 186) (Appendix A, Figure 2). The rare state-listed species that occur in the vicinity of the park are the Pied-billed Grebe *(Podilymbus podiceps)* and the Threespine Stickleback *(Gasterosteus aculeatus)*. The presence of the Threespine Stickleback was corroborated with positive identifications in three locations in Olmsted Park. However, neither direct observations of the Pied-billed Grebe, nor nesting sites of the animal were confirmed. The Pied-billed Grebes travel north in the spring and summer to breed. However, nesting occurs erratically, as a pair may breed in a suitable area one year and never return. Accordingly, it is likely that the Pied-billed Grebe is an occasional visitor to the area.

4.1.1 Wards Pond

Wards Pond, situated at the southern most section of the Emerald Necklace, is naturally protected from urban noise by the geologic knob and kettle formation in which it lies, i.e. steep embankments. The Wards Pond area is not a heavily used pedestrian corridor compared to other areas along the Necklace, and the majority of people who frequent the area do so for recreational purposes. These factors in concert with a healthy assemblage of vegetation lend to the area's wildlife habitat value, as evidenced by the diversity of species observed in numerous visits to the pond.

Wards Pond is fed by an overflow from Jamaica Pond, as well as groundwater discharge. Vegetation associated in the periphery of this pond is on the whole in a natural state, and may be characterized as structurally heterogeneous, with aquatic submergents and emergent, groundcover, shrub, sapling, and canopy vegetation. A nearly complete band of swamp loosestrife *(Decodon verticillatus)* (emergent vegetation) encircles the pond with a variety of shrubs on the periphery including glossy buckthorn *(Rhamnus frangula)*, weeping willow *(Salix babylonica)*, river birch *(Betula nigra)*, gray birch *(Betula populifolia)*, paper birch *(Betula papyrifera)*, arrowwood *(Viburnum dentatum)*, and tulip tree. There are significant clusters of jewelweed *(Impatiens capensis)* in patches with small patches of Japanese knotweed *(Polygonum cuspidatum)* invading and some multiflora rose *(Rosa multiflora)*, as well as narrow-leaved cattail *(Typha angustifolia)* on the southwestern bank. Other species such as silky dogwood *(Cornus amomum)*, blue-flag iris *(Iris versicolor)*, sensitive fern *(Onoclea sensibilis)* and scattered patches of purple loosestrife *(Lythrum salicaria)*, and buttercup are also present.

Groundwater discharge along the southern perimeter of the pond, adjacent to and beneath the boardwalk, is creating an elevated wetland system. Individuals of arrowwood are also found in this area with red maple *(Acer rubrum)* saplings, and scattered individuals of common elderberry *(Sambucus canadensis)*. On the embankment at the

southern section of Wards Pond, a significant stand of tartarian honeysuckle *(Lonicera tatarica)* exists with staghorn sumac. Glossy buckthorn and Japanese knotweed form thick stands of vegetation along the southern embankment, and along with tree-of-heaven *(Ailanthus altissima)* are the predominant exotics in this area. A canopy of mature trees exists on the northern and western portions of the pond, dominated by black oak *(Quercus velutina)*.

The water clarity within the pond is the highest compared to other areas of the Necklace. Factors that help to maintain the high water quality levels in Wards Pond are the lack of direct discharge from storm drains, the depth of the pond, and the established vegetation surrounding the pond. Only one area on the northwestern shoreline of Wards Pond is denuded of vegetation. In addition, the Canada Goose *(Branta canadensis)* population resident to Leverett Pond and areas downstream has not descended upon Wards Pond. The goose absence decreases the potential for the system to become eutrophic, as a resident population of geese leads to an abundance of fecal material and detritus from public feeding of the animals and negatively impacts the water quality in affected/infested areas. This scenario is documented downstream in Leverett Pond, where public feeding of the resident goose population has created a positive feedback mechanism that negatively affects water quality. The mechanism breaks down as follows:

1. Residents feed geese from pond shoreline,
2. Feeding areas become denuded of vegetation with continued and increased public access,
3. Goose population increases with continued and increased public feeding,
4. Water quality decreases with direct discharge of goose fecal material and sediment (active erosion with non-existent vegetative cover),
5. Breakdown of fecal material by bacteria reduces the free oxygen in the watercolumn available to aquatic species,
6. Nutrients released through fecal material decomposition supports algal blooms, which increases turbidity and the biological oxygen demand, and disturbs the production/respiration balance in the ecosystem.

This type of mechanism can be broken by actively planting shrub vegetation adjacent to the shoreline, which limits pedestrian access and discourages shoreline access by geese. Detailed suggestions follow in Section 6.1.4.

Species observed in Wards Pond include a variety of avian, insects, amphibians, and freshwater fishes, as tabulated in Appendix B, Species Observations. As mentioned above, the relative isolation of this area alongside a diverse vegetative community supports a diversity of wildlife habitat.

4.1.2 Nickerson Hill/ Babbling Brook/ Spring Pond

A steep drumlin, Nickerson Hill, between Wards Pond and Willow Pond provides high quality wildlife habitat to an array of mammals, birds and insects. The tree canopy is predominantly complete with open areas at the higher reaches of the hill. Vegetation on the north-facing slope is comprised of a well-developed sapling layer dominated by yellow birch *(Betula alleghaniensis)* and a diminished shrub layer. The shrub species are present where canopy gaps exist, and are dominated by glossy buckthorn *(Rhamnus frangula)* with scattered individuals of small Solomon's Seal *(Polygonatum biflorum)*. Canopy species consist of northern red oak *(Quercus rubra)*, black oak *(Quercus velutina)*, American beech *(Fagus grandifolia)*, and river birch *(Betula nigra)*. Saplings from the well-developed canopy are also present.

At the upper reaches of Nickerson Hill, gaps in the canopy give way to an assemblage of meadow species consisting of various grasses (Family POACEAE), fecsues, path rush, orchard grass, asters, in addition scattered patches of bittersweet and staghorn sumac. Vegetation on the southern slope consists of a mature canopy of black oak *(Quercus velutina)*, northern red oak *(Quercus rubra)* and white oak *(Quercus alba)*, and a shrub layer of glossy buckthorn *(Rhamnus frangula)*.

The relative isolation of Nickerson Hill provides wildlife habitat, in addition its intrinsic features support species utilization. The exposed soils on the pathways weaving through Nickerson Hill provide a source of sediment to seed eating birds, such as the Field Sparrow *(Spizella pusilla)*, Song Sparrow (*Spizella melodia)* and the Chipping Sparrow

(Spizella passerina), as well as dusting sites for a variety of avian species. The well-developed canopy provides a mast crop for a variety of avian and mammals, including American Crow *(Corvus brachyrhynchos)*, Blue Jay *(Cyanocitta cristata)*, Eastern grey squirrel *(Sciurus carolinensis)*, meadow voles *(Microtus pennsylvanicus)*, and Eastern chipmunk *(Tamias striatus)*. The open-meadow type ecosystem provides habitat for meadow voles *(Microtus pennsylvanicus)* and moles, deer mice, Eastern cottontail *(Sylvilagus floridanus)*, and insects, such as the field cricket *(Gryllus pennsylvanicus)*, butterfiles (Lepidoptera spp.) and ants (Hymenoptera spp.).

The babbling brook, upon exiting Wards Pond, is confined by moderately steep topography and flows adjacent to Pond Avenue and ultimately discharging into Willow Pond. The stream is shaded by a densely vegetated shrub community comprised of red maple saplings, arrowwood, silky dogwood, buckthorn, gooseberry *(Ribes hirtelleum)*, as well as herbaceous species jewelweed and skunk cabbage *(Symplocarpus foetidus)*. A significant colony of Japanese knotweed lines the brook on the western side and provides a thick screen to adjacent Pond Avenue traffic. The dense vegetation provides a temperature control of the stream allowing higher dissolved oxygen concentrations with cooler temperatures. One area on the western side of Babbling brook, proximal to the confluence with Willow Pond, is completely denuded of vegetation, and actively contributing sediment to the stream. Water in the stream is approximately 4 – 6 inches deep and 2 – 3 feet wide on average.

A bordering vegetated wetland system exists adjacent to Jamaica Way in the vicinity of the previous location of MDC ice rink. This wetland system feeds into Spring Pond, the sole remainder of the 5 proposed natural history pools created by Olmsted in the late 1800's. This wetland system is a very dense entanglement of shrub swamp, dominated by purple loosestrife, narrow-leaved cattail *(Typha angustifolia)*, climbing nightshade *(Solanum dulcamara)*, jewel-weed, and arrowwood. The removal of equipment upon the ice-rink closure increased the amount of standing water in the wetland for a period of time significant enough to result in a die-back of vegetation, specifically box elder *(Acer negundo)*, black cherry *(Prunus serotina)*, and red maple *(Acer rubrum)* trees, within the wetland. The increase in water contributed to high-energy flows and eroded a small channel between the wetland and Spring Pond exposing tree roots and depositing sand and gravel within this area. The channel transports water from the wetland to Spring Pond in times of overflow from episodic events or engineering failure (as with the MDC ice rink), and does not occur on a seasonal basis.

Spring Pond, a small, linear-shaped, shaded pond just upstream from Willow Pond, is habitat to the three-spine stickleback *(Gasterosteus aculeatus)*, a small (maximum length = 10 cm) fish currently listed as a threatened species by the Massachusetts Division of Fish and Wildlife Natural Heritage and Endangered Species Program. The sticklebacks in Olmsted Park are considered to be the southern-most completely freshwater population of sticklebacks in the country. Sticklebacks were observed within Spring Pond, in the channel connecting Spring and Willow Ponds, and in Willow Pond at the outfall from Spring Pond.

Spring Pond contains water approximately 2 feet deep, and is fringed by glossy buckthorn, with red maple saplings and pin oak *(Quercus palustris)* on the periphery. While the pond does receive overflow discharge from the upstream wetland, the primary water source is groundwater, hence its name. Due to its source, the water in Spring Pond is clear and of high quality. Water exiting Spring Pond flows through a meandering two-foot wide channel and discharges directly into Willow Pond via a stone box culvert.

4.1.3 Willow Pond

Willow Pond, situated between Wards Pond and Leverett Pond, receives discharge from two sources, the babbling brook and Spring Pond. Vegetation surrounding Willow Pond is comprised of mature oaks with a sapling understory on the eastern side and a variety of shrubs, saplings and herbaceous species on the western side, including red-osier dogwood *(Cornus stolonifera)*, sweet pepperbush *(Clethra alnifolia)*, American bittersweet *(Celastrus scandens)* weeping willow *(Salix babylonica)* barberry, Japanese knotweed and Virginia rose *(Rosa virginiana)*. A dense colony of herbaceous vegetation exists at the outfall from Babbling brook. The vegetation is confined to two small island

areas and is comprised of broadleaf arrowhead *(Sagittaria latifolia)*, pickerelweed *(Pontederia cordata)*, barnyard grass *(Echinocloa crusgalli)*, jewelweed *(Impatiens capensis)*, purple loosestrife *(Lythrum salicaria)*, three-square bullrush *(Scirpus americanus)* and mannagrass *(Glyceria canadensis)*. The western shoreline of Willow Pond is bounded manicured lawn with a shrub fringe, while the east is forested. Willow Pond exhibits evidence of environmental stresses from oil contamination. LEC was unable to sample aquatic species due to the thick organic material and soft sediments on the subsurface of Willow Pond.

4.1.4 Leverett Pond

Leverett Pond, the largest pond within Olmsted Park, is a long, linear shaped pond located at the northern end of Olmsted Park. The babbling brook discharges into Leverett Pond, although the brook is not day-lighted along its length from Willow Pond. A culvert on the southeastern side of the pond, in the vicinity of Daisy Field, also feeds into the pond. The areas surrounding the pond are vegetated by manicured lawn with a mature tree canopy. In the majority of areas, manicured lawn extends to the pond shoreline, although active planting of shrubs in the past few years along the western shoreline of the pond has replaced the lawn cover in some areas. The tree canopy is comprised of sugar maple *(Acer saccharum)*, pin oak *(Quercus palustris)*, sweet gum *(Liquidambar styraciflua)*, black cherry *(Prunus serotina)*, black oak *(Quercus velutina)*, northern red oak *(Quercus rubra)* and box elder *(Acer negundo)*. Shrub vegetation along the western bank dominated by purple loosestrife by scattered individuals of sweet pepperbush *(Clethra alnifolia)* and arrowwood *(Viburnum dentatum)*.

A feature unique to Leverett Pond that provides excellent wildlife habitat is the three vegetated islands located on the western boundary of the pond. An Olmsted creation, the islands are vegetated by river birch *(Betula nigra)*, Eastern poplar *(Populus deltoides)*, paper birch *(Betula papyrifera)* white ash *(Fraxinus americana)*, and tupelo *(Nyssa sylvatica)*. The narrow channels between the shoreline of the pond and of the islands lend to the diversity of habitats available in Leverett Pond for aquatic species. Further, the islands provide excellent shade, as well as numerous overhangs, created by bank and vegetation, and cavities, providing excellent habitat for reptiles, amphibians and avian species. This habitat diversity leads to species diversity, which was evidenced by the variety of aquatic species found in Leverett Pond. Intraspecies comparison revealed a spectrum of sizes indicative of functional breeding and recruitment amongst the species observed (Appendix B). The preferred habitat for aquatic species within Leverett Pond was hard-bottomed areas adjacent to steep banks. The steep banks are conducive to micro-scale upwelling areas, which bolster atmospheric exchange and transport inorganic nutrients to the euphotic zone for production. The recent improvement of wire-mesh covered rocks along portions of the banks on the western bank of Leverett Pond supports aquatic habitat by increasing the surface area of the banks, which stimulates oxygen exchange, and promoting algal growth.

There are several areas in Leverett Pond that require immediate attention to improve the water quality. The most visible of these is a large island at the northern end of the pond that consists of sediment, primarily road sand, deposited by the Village Brook culvert. Discharge of sediments, including road sand, from the Village Brook drainage area negatively impacts water quality. Best management Practices should be improved in the watershed if restoration efforts are to have long-term positive benefits. Cobble swales that direct discharge to Leverett Pond also are an active sediment source to the pond. In addition, sediment from Daisy Field is being actively deposited in Leverett Pond. Numerous areas are completely denuded of vegetation are contributing sediment to pond when overland flow occurs following a storm event. The erosion of these areas will increase the turbidity of Leverett Pond, inhibiting primary production and negatively impact the food web from its inception. One of the denuded areas on the western edge of the pond is frequently used for duck and goose feeding. As mentioned in Section 4.1.1, this activity is negatively affects the water quality in Leverett Pond.

4.2 Riverway

The Riverway area extends from Route 9 to the Back Bay Yard. A continuos footpath parallels the river along the eastern and western side of the river south of Route 9. The areas landward of the footpath are vegetated by a mature trees canopy and manicured lawn areas that occupy the groundcover to the river's banks in most areas. On the riverside of the footpath, the vegetation consists manicured lawn, with occasional ornamental shrubs. Aggressive monocultures, common reed *(Phragmites australis)* and knotweed, comprise the primary bank vegetation. *Phragmites* is an emergent plant growing within the watercourse, while Japanese knotweed require the dryer embankment conditions. The invasion of *Phragmites* has constricted the river's channel substantially in numerous areas along this portion of the Necklace, i.e. between Brookline Avenue and Jamaicaway, the eastern channel through the Island Bridges area, and the eastern side of the Muddy River between the Chapel Street Bridge Area and Back Bay Yard. Colonization of *Phragmites* increases sediment deposition in affected areas through sediment trapping (Section 6). Sediment deposition will further impede the ability of the river to carry its flow downgradient through coincident decreases in the water column and channel width. The existing condition descriptions of the Riverway are divided into two sections, south and north of Longwood Avenue. Species observations of the Riverway are listed in Appendix B.

4.2.1 Route 9 to Longwood Avenue

A mature tree canopy comprised of northern red oak *(Quercus rubra)*, American elm *(Ulmus americana)*, and white ash *(Fraxinus americana)* exists adjacent to the eastern bank of the river, and provides habitat to avian species and squirrels. However, wildlife habitat is variable south of Brookline Avenue (Riverway South), as a segment of this stretch is culverted. The river daylights north of Washington Street, where the channel is lined with rip-rap.

The rip-rapped section of the river, while narrow, provides significant wildlife habitat because of the diversity of vegetation present and the high degree of channel entrenchment, i.e. steep banks, that provide shelter and isolation from the dense urban environment surrounding this area. The river is completely shaded by a mature canopy of American elm *(Ulmus americana)*, white ash *(Fraxinus americana)*, and red maple *(Acer rubrum)*. Shrub species present along the banks include glossy buckthorn *(Rhamnus frangula)* and arrowwood *(Viburnum dentatum)*, with some Japanese knotweed *(Polygonum cuspidatum)* and tree-of-heaven *(Ailanthus altissima)*. A sole red mulberry *(Morus Rubra)* provides a nectar source for nectar feeders such as hummingbirds, butterflies and bees, as well as an abundant mid to late summer fruit source. Downstream from this section, as the river parallels Brookline Avenue, the channel is completely constricted by *Phragmites*.

North of Brookline Avenue, the river bifurcates and rejoins at the pedestrian bridge just south of Netherlands Road. The eastern branch of the channel is choked by *Phragmites*, while the western channel is clear. *Phragmites* colonization and growth can be inhibited by shade, and the mature canopy cover along the western channel provides adequate shade to impede growth. *Phragmites* also tends to colonize areas with shallow banks. This is evidenced by the growth on shallow banks of the eastern channel of the river, compared to no growth adjacent to the steep bank of the western channel. The mature tree canopy of black oak *(Quercus velutina)*, northern red oak *(Quercus rubra)*, and pin oak *(Quercus palustris)* on the Riverway Island provides habitat to avian species and small mammals. Though the groundcover consists primarily of manicured lawn, the seed source of the oak trees provides a food source for these animals.

Downstream of the island bridges area, the channel is linear (man-made) and the vegetative cover types consist of a mature oak canopy, with manicured lawn groundcover. The shrub layer consists of Japanese knotweed, with scattered individuals of gray birch *(Betula populifolia)*. The mature tree canopy shades the watercourse and prevents the colonization of *Phragmites*. Cobble swales contribute sediment to the river in this area decreasing the water quality. The raceways primarily transport stone dust from the walkway paralleling the river.

4.2.2 Longwood Avenue to Old Sears Tower

Vegetation along this segment of the river is comprised of a mature oak canopy landward of the footpath. *Phragmites*, river birch *(Betula nigra)*, glossy buckthorn and gray birch *(Betula populifolia)* dominate the bank vegetation, and provide a thick screen in areas. In addition to *Phragmites* and Japanese knotweed, yellow iris *(Iris pseudacorus)*, a non-native invasive species, is present in the northern section of the Riverway. Similar to Leverett Pond, public waterfowl feeding areas are completely denuded of vegetation and contributing sediment and fecal material directly into the watercourse.

Two densely vegetated islands located on the eastern side of the Riverway. Canopy vegetation consists of red maple *(Acer rubrum)*, river birch, paper birch, pin oak *(Quercus palustris)* and weeping willow *(Salix babylonica)*. The islands increase habitat diversity for aquatic and land animals. In addition, the islands provide a significant refuge for species within this segment of the Necklace due to the minimal amount of open space and heavy vehicular traffic at this location.

Standing tree boles in the northern portion of the Riverway provide excellent habitat to avian cavity nesters, such as the Northern Flicker *(Colaptes auratus)*. The overhangs and snags from the island provide basking and perching sites for reptiles and waterfowl species. Three bur oak trees *(Quercus macrocarpa)* are also present in this area.

Phragmites may provides limited wildlife habitat. For instance, thick stands of the reed creates a thick screen along the banks of the river. Screening is important in urban areas to dampen the constant noise. A wall of *Phragmites* also provides escape cover. However, the negative effects of *Phragmites* far outweigh the positives. The common reed does not provide essential wildlife habitat functions, i.e. food source, nesting or breeding habitat. Non-native aggressive exotics reduce the overall species diversity in affected areas, because only highly adaptable or urban species can adjust. The problems associated with urban wildlife species parallel the invasive vegetation as these species breed quickly and establish large populations that are without natural predators. The large populations degrade habitat with an abundance of waste material, and because the volume of waste outweighs the natural capacity of the system, much of the material is not decomposed. An ecosystem can quickly become out of balance through the introduction of non-native exotics.

While the Emerald Necklace flows northeast from Wards Pond to its confluence with the Charles River, the river meanders at a 90° angle at the Old Sears Tower and flows southeast for 0.5 mi. The river returns to a northeast trend with a 90° bend at Clemente Field. At the Back Bay Yard, the river flows through 2-six foot diameter culverts. The configuration of the channel, i.e. the inadequately designed culverts are responsible for upstream flooding problems.

4.3 Back Bay Fens

The Back Bay Fens extends from Old Sears Tower to Charlesgate. The Back Bay Fens is used intensively by the public due to the wide flanks of parkland adjacent to the river. This area is intensely manicured and landscaped and contains a war memorial, a ball-field and playground, a rose garden and an expansive community garden, the Victory Gardens. The dominant vegetation within this area is common reed *(Phragmites australis)*, which occupies in excess of 5-acres of the watercourse. The extent and density of *Phragmites* screens park vistas from footbridges and road bridges. The *Phragmites* is in excess of 20-feet tall in areas, and the width of the stands range from 5 to 25 feet. By creating a thick screen between the river and the park, the presence of *Phragmites* fosters illicit activity and degrades overall park quality with the increases in rubbish and human odors associated with this type of behavior. Additionally, the public safety issue and rubbish reduces the aesthetic experience for the city resident. The Back Bay Fens will be described in two sections, Old Sears Tower to Clemente Field and Clemente Field to Charlesgate. Species observations for this area are described in Appendix B.

4.3.1 Old Sears Tower to Clemente Field

As discussed in Section 4.2.2, the river flows southeast to Clemente Field. At the Back Bay Yard the rivers is directed through 2 culverts. The river daylights approximately 0.13 mi. southeast of the Old Sears Tower. Upon daylight, the river appears like a linear pond, as flow is directed through culverts just a short distance downstream (0.06 mi.) at Avenue Louis Pasteur. Though small, this area provided ample wildlife habitat with mature canopy vegetation and numerous basking and perching sites within the watercourse. Further, the entrenched channel provides seclusion for wildlife and provides a buffer from the noise of heavy vehicular traffic that parallels the river on either side.

The mature canopy consists of river birch *(Betula nigra)*, paper birch *(Betula papyrifera)*, northern red oak *(Quercus rubra)*, pin oak *(Quercus palustris)*, black oak *(Quercus velutina)*, silver maple *(Acer saccharinum)*, and norway maple *(Acer platanoides)*. Shrub community is dominated by glossy buckthorn *(Rhamnus frangula)* with scattered individuals of arrowwood *(Viburnum dentatum)*, honeysuckle and saplings from the canopy. Due to the shade cover and relatively steep banks, no *Phragmites* is present. Minimal Japanese knotweed is present.

The river daylights southeast of Louis Pastuer, and two patches of *Phragmites* are present where gaps in the canopy exist. Canopy vegetation is similar to the upstream assemblage. Sediments are "soft" with a high amount silt and organic material.

4.3.2 Clemente Field to Charlesgate

At Clemente Field, the river bends 90° to flow northeast towards the Charles River. Canopy vegetation is comprised of pin oak *(Quercus palustris)*, black oak *(Quercus velutina)*, northern red oak *(Quercus rubra)* and weeping willow *(Salix babylonica)*. Hackberry *(Celtis occidentalis)*, arrowwood *(Viburnum dentatum)*, and glossy buckthorn *(Rhamnus frangula)*. Blue flag *(Iris versicolor)* and tartarian honeysuckle *(Lonicera tatarica)* are also present. Small patches of *Phragmites* exist coincident with canopy gaps. Northeast of Clemente Field, the channel meanders through the Back Bay Fens proper. Approaching the Museum of Arts, the canopy vegetation transitions to aggressive sapling along the banks, and no mature trees are present. Shrub vegetation consists of arrowwood *(Viburnum dentatum)*, buttonbush *(Cephalanthus occidentalis)*, with climbing nightshade *(Solanum dulcamara)* throughout. The submerged aquatic species, millfoil, is present throughout the watercourse.

The lagoon directly opposite the Museum of Fine Arts is the one of the few hard-bottomed areas within the Back Bay Fens. The hard bottom and steep banks provide wildlife habitat for fish species, such as the common carp (*Cyprinus carpio)*, some in excess of 2-feet, pumpkinseed sunfish *(Lepomis gibbosus)* and bluegill sunfish *(Lepomis macrochirus)*. The majority of fish activity observed was sessile, with little active swimming, most likely to conserve oxygen. Vegetation surrounding the lagoon is dominated by purple loosestrife *(Lythrum salicaria),* false indigo *(Amorpha fruticosa)*, and hawthorn *(Crataegus spp.)*. The hawthorns provide an excellent nectar source for nectar feeders. The tree canopy is comprised of pin oak *(Quercus palustris)*, northern red oak *(Quercus rubra)*, gray birch *(Betula populifolia)* and ornamental cherries.

Downstream of the lagoon area, the river flows northeast. The vegetation on either side of the river is weeping willow *(Salix babylonica)*, pin oak *(Quercus palustris)*, northern red oak *(Quercus rubra)*, false indigo *(Amorpha fruticosa)*, tupelo *(Nyssa sylvatica)*, box elder *(Acer negundo)* and honey locust. Manicured lawn is the primary groundcover throughout the Back Bay Fens. Adjacent to the Stony Brook Gatehouse is a large island of road sand deposited from the adjacent culvert. The deposit is the result of road sanding and decreases the channel capacity of the river thereby restricting flow. The deposit eliminates Land Under Waterbodies and habitat for aquatic species, though is does provide perching sites for water birds, such as Herring Gulls *(Laurs argentatus)*, Mallards *(Anas platyrhynchos)* and the Canada Goose *(Branta canadensis)*.

The meandering river is flanked by dense colonies of *Phragmites* from the Stony Brook Gatehouse north to Charlesgate. The only exception to the thick stands of *Phragmites* is an equally dense patch of narrow-leaved cattail *(Typha angustifolia)* interspersed with purple loosestrife *(Lythrum salicaria)* on the western bank of the river south of the Agassiz Bridge. The stands of *Phragmites* range in width from 5 to 25 feet and reeds are in excess of 20-feet tall. These thick colonies of *Phragmites* create an almost impenetrable barrier along the banks of the river, eliminating historic vistas, reducing wildlife species utilization, increasing the potential for deviant behavior and decreasing the aesthetic experience of the park for city residents.

One area adjacent to Mother's Rest demonstrates that *Phragmites* may be outcompeted by other vegetation if enough shade exists. In this area, *Phragmites* reeds are stunted by the shade of a silver maple *(Acer saccharinum)*. The silver maple's preferred habitat is riparian zones. This rapid growing species establishes itself along the river banks, and grows to significant heights in a relatively short amount of time. This portion of the Back Bay Fens, approximately 40-linear feet, is the only spot north of Stony Brook gatehouse where *Phragmites* is absent.

The wildlife habitat of the Back Bay Fens is diminished due to the presence of *Phragmites*. As discussed above, the presence of *Phragmites* reduces overall species utilization for a number of reasons; the absence of diversity, absence of structural heterogeneity, and most importantly lack of viable habitat. *Phragmites* does not provide a food source, or nesting habitat for the majority of avian species known to frequent the area. *Phragmites* was observed to provide perching sites for Red Winged Blackbirds and English Sparrows, as well as limited escape cover for English sparrows and Blue Jays *(Cyanocitta cristata)*. Perching will occur regardless of vegetation type, as the activity is morphology dependent rather than nutrient dependent. As habitat characteristics diminish, the diversity of species will decline because the ecosystem can not provide essential services.

4.4 Charlesgate

Charlesgate extends north from the Back Bay Fens to the river's confluence with the Charles River. The Charlesgate area is fragmented from Back Bay Fens by the Massachusetts Turnpike, which trends in an east/west direction. Charlesgate is not frequently visited by the public, due to the sinuous configuration of roads, highways and bridges that weave through the 0.25-mile stretch of the river. The banks of the river, i.e. from mean high water to mean low water, are stabilized with rip-rap. The banks of the river are vegetated with mature trees, including red pine *(Pinus resionosa)* and American elm *(Ulmus americana)*. Stumps along the flanks of the river remain from felled American elm trees afflicted with American elm disease. While the Muddy River is daylighted through the majority of the Charlesgate area, the northern-most section flows through a culvert, for a distance less than 0.5 miles, to the river's confluence with the Charles River. Due to intensity of road infrastructure and minimal vegetation, the capability of this area to provide basic wildlife habitat is impaired.

5. Ecosystem Functions and Values

The shifts in ecosystems from natural and diverse assemblages of vegetation or fauna to ecosystems dominated by one species, either native or exotic, have been documented for some time and may be linked to human disturbances. These ecosystem shifts are documented to occur with changes in vegetation through changes in hydrologic regime of an ecosystem, e.g. saltmarsh cordgrass *(Spartina patens)* to common reed *(Phragmites australis)* with changes in salinity, but they may also occur with increases in nutrient loading or the introduction of exotic faunal species, i.e. zebra mussels or European Starlings *(Sturnus vulgaris)*. Perturbations in ecosystem balance can rapidly deteriorate the quality of natural systems for two reasons, lack of predators for exotic fauna and the inability of native species to utilize the monotypic and/or non-native invasive vegetation for primal requirements.

The intensity of development surrounding the Emerald Necklace, the numerous culverts within the Muddy River watershed and associated sediment and nutrients, and the low gradient of the river flow, combined with the absence of

routine maintenance of the historic landscape allowed for the introduction of non-native exotics, Japanese knotweed and *Phragmites*. Glossy buckthorn *(Rhamnus frangula)* and tree-of-heaven *(Ailanthus altissima)* were formally introduced at the early part of the 20th century.

Phragmites expansion has been documented in freshwater, oligohaline and mesohaline tidal wetlands. Reproduction of *Phragmites* is controlled by rhizomes, which produce new shoots through nodal roots, rather than by seed germination (Chambers, 1999). Nutrient loading in wetland systems may be responsible for *Phragmites* expansion, as the reed appears to outcompete tidal wetland plants for other limiting resources, i.e. light, when nutrients are in excess (Levine, 1998). This scenario has been documented in the Florida Everglades with a shift from a *Cladium*-dominated wetland to one dominated by *Typha* with increases in phosphorus. *Phragmites* can be a fast-growing species, with rhizome growth up to 30-feet per annum in nutrient-rich sites; average growth rates are 2-3 feet per year.

The expansion of *Phragmites* into North American wetlands has been documented to decrease overall plant diversity. The capacity of *Phragmites* wetlands to provide resting, feeding, and breeding areas are greatly diminished compared to the pre-*Phragmites* ecosystem. Additionally, the coincident change in habitat structure and decrease in vegetation diversity excludes utilization by large wading birds, and marsh specialist species are replaced by generalists, leading to an overall reduction in species richness (Benoit & Askins, 1999).

Phragmites dominated wetlands are associated with high sedimentation rate (Harrison & Bloom, 1977). This feature may be appealing in marshes subject to sea-level rise. However, it is unattractive in areas with flooding problems, because *Phragmites* will impede the natural flow of the watercourse. This happens in two ways; thick stands of *Phragmites* occupy a percentage of the watercourse and narrow the channel, and the accelerated sedimentation rate caused by *Phragmites* reduces the watercolumn. Not only do these factors exacerbate flooding problems, but they also reduce access by aquatic species.

6. Proposed habitat improvements

The ecosystem of the Emerald Necklace will benefit from incremental changes in habitat structure, with the goal of rehabilitating the historical landscape in a manner that will allow nature to eventually take control of the rehabilitated ecosystem. Creation of a self-sustaining ecosystem is necessary to minimize the continual maintenance of the park. This is an ultimate goal that will not be realized until the majority of non-native invasive species have been eradicated. The removal of *Phragmites* will be greatly simplified if it can be done coincident with watercourse dredging.

When analyzing the potential for this urban ecosystem, realistic goals should be in place. This system will never be pristine; it is an area subject to a good deal of pedestrian traffic and is bounded by busy city streets for much of its fetch. Numerous culverts from densely developed urban areas discharge into the Muddy River. However, by implementing a habitat restoration protocol through vegetation management and in conjunction with implementation of Best Management Practices (BMP's), there is an excellent chance for the natural capacity of the ecosystem to improve.

Proposed habitat improvements are categorized into three units; *Phragmites* removal, habitat restoration and no-action. Few areas of the Emerald Necklace fall into the third category. The habitat improvements are organized by the three primary Necklace links, Olmsted Park, Riverway and Back Bay Fens.

6.1 Olmsted Park

Olmsted Park is the most natural region of the Emerald Necklace. However, improvements associated with BMP's are necessary to improve water quality. In addition, the removal of exotic vegetation, and stabilization of actively

eroding areas are necessary to improve the natural capacity of the resource area to provide wildlife habitat to a diverse assemblage of animals.

6.1.1 Wards Pond

Wards Pond is one of the more desirable ecosystems within the Emerald Necklace, and is in little need of restoration, with the exception of exotic vegetation removal. The removal of Japanese knotweed, Tree-of –Heaven, Glossy buckthorn, and Tartarian honeysuckle *(Lonicera tatarica)* in the southeastern portion of the pond and replacement with indigenous species will increase vegetative diversity in this ecosystem. The planted species can satisfy the wildlife requirements and the historic nature of the landscape by selecting compatible species from Olmsted's historic list. The denuded area on the northwestern shoreline negatively impacts water quality and could be reintroduced with indigenous species likely to survive the existing conditions, further stabilizing the area while providing valuable habitat.

6.1.2 Nickerson Hill/ Babbling Brook/ Spring Pond

These areas would benefit from the removal of exotic vegetation, namely Japanese knotweed along the banks of Babbling brook and the removal of Glossy buckthorn throughout Nickerson Hill and surrounding Spring Pond. Pathways throughout Nickerson Hill can be modified to retard erosion.

6.1.3 Willow Pond

The Willow Pond ecosystem has the highest potential for responding to an enhancement program. Two sources of clean water from Spring Pond and Babbling brook are the perfect ingredients to create a desirable ecosystem. The high-oxygen demand bottom sediments of Willow Pond degrade the aquatic habitat by increasing the biological oxygen demand and decreases oxygen concentration within the pond. Additionally, the bottom sediments contain high concentration of polyaromatic hydrocarbons (PAH's) and metals. Enhancement of the aquatic habitat through dredging will create a desirable habitat for fish populations and create another viable area for recreational fishing, in addition to the currently used Ward's Pond and Jamaica Pond.

The western shoreline of the pond can be enhanced by planting shrub vegetation, and removing the Purple loosestrife and American bittersweet *(Celastrus scandens)*. The Japanese knotweed at the northern end of the pond detracts from wildlife habitat quality. Planted species should be selected based on habitat value, microhabitat requirements for specific species growth, and historic significance.

6.1.4 Leverett Pond

The shoreline of Leverett Pond could be enhanced by fostering a dense shrub layer along the banks of the pond. The removal of exotic vegetation, namely purple loosestrife *(Lythrum salicaria)* and glossy buckthorn *(Rhamnus frangula)* and replacement with indigenous vegetation will increase habitat diversity. In addition, the stabilization of actively eroding areas surrounding Leverett Pond, i.e. adjacent to Daisy Field and on the eastern bank of the pond, will improve water quality.

The planting of shrubs around the waterfowl feeding area on the western bank of the pond will discourage public access. The introduction of a dense shrub layer will discourage shoreline access from Canada Goose *(Branta canadensis)*. In conjunction, public awareness placards might be placed along the walkway to discourage public feeding of the birds as well.

The removal of the large island created by road sand in the northern portion of the pond will increase the water quality and improve aquatic habitat within Leverett Pond. While this island provides perching sites for birds, the birds that frequent the island are large droves of Herring Gulls *(Laurs argentatus)*, Canada Goose *(Branta canadensis)* and Mallard *(Anas platyrhynchos)*. The removal of this island will not reduce the desirability of this area

species, but instead will increase habitat for aquatic species. In conjunction, the routine maintenance of storm drains with regular street sweeping will also improve water quality.

6.2 Riverway

The Riverway section of the Emerald Necklace will benefit from complete *Phragmites* removal. The sections most in need of *Phragmites* removal are areas where the channel is completely constricted by the reed, specifically between Brookline Avenue and Jamaicaway, the eastern channel in the Island Bridges area, and at the Back Bay Yard area. Between Longwood Avenue and the Old Sears Tower, dense stands of *Phragmites* eliminate the historic vistas from pedestrian footbridges, road bridges and along the shoreline of the river. While some of these areas are relatively short in length, the existing *Phragmites* is a seed source for the establishment of other colonies. Dredging of the *Phragmites* rootstock will provide immediate results. However, without follow-up maintenance, these efforts will surely be futile.

The soft-bottom sediments of the Riverway contain a significant amount of silt and organic material and their removal would reduce the oxygen demand on the aquatic ecosystem. This goal can be achieved by dredging the watercourse. At the same time, the dredged channel should be shelved to provide areas for planting emergent vegetation. Planting emergent aquatic vegetation will increase the structural heterogeneity of the ecosystem, which is greatly lacking in this section of the river, and create habitat for reptiles, amphibians and avian species. The lack of shrub vegetation precludes the settlement of certain avian species, because the habitat requirements are not present. For instance, species such as the Gray Catbird *(Dumetella carolinensis)* and Yellow Warbler *(Dendroica petechia)* prefer shrubs 4-6' tall for nesting, few of which are present in this section of the Necklace. As a result, the bird is forced to leave the Necklace to find suitable nesting sites. The continual narrowing of vegetative species diversity will, with time, eliminate habitat for a variety of animal species as well as foster the propagation of urban animal species.

The shrub zone vegetation along the shoreline of the Riverway is dominated by either *Phragmites* (as emergent vegetation within the watercourse) or Japanese knotweed (along the banks of the river), the removal of these species along with the planting of shrubs conducive to wildlife will increase the available habitat. The denuded banks are responsible for contributing sediment to the watercourse, and the stabilization of these areas will reduce the suspended solid inputs. Additionally, a habitat enhancement program can be adopted to include the introduction of wildlife for nectar feeders and aesthetic values, as well as installing and maintaining nesting boxes for certain target species. If nesting boxes were to be installed in any area of the Emerald Necklace, the boxes must be diligently maintained in the springtime to ensure success of designated occupants. Planted species may be selected from of list of compatible species from both the historic and wildlife perspective and include such species as swamp azalea *(Rhododendron viscosum)*, tupelo *(Nyssa sylvatica)*, silky dogwood *(Cornus amomum)*, witch-hazel *(Hamamelis virginiana)*, and winterberry *(Ilex verticillata)*.

A considerable amount of the suspended solid inputs to the Riverway originate from the stone dust pathways that parallel both sides of the river. The stone dust is transported to the river with minor amounts of rainfall. To prevent this, a small berm could be placed on the riverside of the pathway. In addition, the cobble swales are conducive to direct discharge of suspended solids to the watercourse. This occurs in two ways. The obtrusive swales exacerbate erosion through their imperviousness, which creates rivulets and gullies between the sides of the swales and the earthen areas surrounding the structures. The eroded material is deposited within the watercourse. Also, the long, linear structures directly discharge turbid water, primarily the stone dust from the pathway. The removal of the cobble swales will prevent further degradation of water quality. The swales present in the Back Bay Fens have the same affect on water quality.

6.3 Back Bay Fens

The Back Bay Fens portion of the Emerald Necklace requires an aggressive approach to invasive vegetation management, as well as maintenance to its heavily accessed parks and pathways. The degree to which *Phragmites*

has established itself within this area of the park presents a higher level of difficulty for eradication than elsewhere in the Necklace. In addition to *Phragmites* removal, the Purple Loosestrife present in certain areas, such as the Lagoon area and within the narrow-leaved cattail *(Typha angustifolia)* colony just south of Agassiz bridge, requires removal.

The removal of established *Phragmites* colonies, including root mats, will maximize the efficiency of the restoration process. The shape of the dredged channel could be conducive to planting emergent vegetation, from both a wildlife habitat and historical standpoint. Plantings in this area may be comprised of species such winterberry *(Ilex verticillata)*, silky dogwood *(Cornus amomum)*, arrowwood *(Viburnum dentatum)*, nannyberry *(Viburnum lentago)* and speckled alder *(Alnus rugosa)*.

As with the areas upstream, the stabilization of actively eroding areas and removal of cobble swales will improve water quality within the Back Bay Fens. In areas where the natural topography necessitates the use of drains, French drains (i.e. crushed gravel) could be used in place of cobble swales to allow for natural seepage of surface runoff as opposed to channelized flow.

The prevention of active contributions of sediment to the watercourse is of greater importance given the area's history of flooding and the dense colonies of *Phragmites*. As discussed in Section 5, *Phragmites* dominated wetlands are effective entrappers of sediment and continually accrete. This may impede water discharge and contribute to bank overflow conditions. In conjunction with the stabilization of eroding areas, the removal of accumulated sediment deposited through culvert discharge, such as in the Stony Brook Gatehouse area, will improve water quality, in conjunction with BMP's implementation.

Upstream of the Agassiz Bridge, in areas absent of *Phragmites*, the shrub vegetation along the banks of the river is variable. These areas would benefit from indigenous plantings to bolster the area's wildlife habitat value. Similar to the Riverway, the Back Bay Fens suffers from a lack of structural heterogeneity, the result of which is incrementally eliminating species utilization through the colonization of monotypic vegetation. To reiterate the primary thesis of this report, the overall species richness in the ecosystem will continue to decline if this pattern goes unabated. An excellent proving ground for plant species introduction is the lagoon area across from the Museum of Fine Arts. Here the thin shrub layer is comprised of purple loosestrife *(Lythrum salicaria)*, false indigo *(Amorpha fruticosa)*,and jewelweed *(Impatiens capensis)* can be replaced by a more diverse assemblage of species that provide habitat for an equally diverse number of animals. Planted species can be selected from the Olmsted's historic list to ensure compatibility with the historical restoration of the landscape. In addition, a dense shrub zone in theses areas will prevent access to the shoreline by geese.

7. Conclusion

A wildlife habitat evaluation and vegatation assessment of the Emerald Necklace in Boston, Massachusetts was performed by LEC Environmental Consultants, Inc, (LEC). The data were collected as part of the Muddy River restoration project sponsored by the City of Boston Parks and Recreation Department.

The Emerald Necklace offers limited wildlife habitat due to the density and extent of non-native invasive species such as common reed *(Phragmites australis)*, Japanese knotweed *(Polygonum cuspidatum)*, purple loosestrife *(Lythrum salicaria)* and glossy buckthorn *(Rhamnus frangula)*. However, because the Emerald Necklace occupies 3.5 miles of almost continuos green space, species do utilize the area, though the quality of habitat is not high. The natural capacity of the resource areas will be substantially improved by increasing vegetative diversity and water quality. These improvements will create an environment conducive to a wide assemblage of aquatic, amphibian, reptilian, avian and mammalian species, with the ultimate goal to create a strong ecological foundation that leads to a sustainable landscape.

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8. Appendix A

Species Observations

Species observed are listed by common and latin names. In parentheses following the name of the species is the number of observations over the course of the study period.

WARDS POND

Fish

Bluegill *(Lepomis macrochirus)* (4)

Large mouth bass *(Micropterus salmoides)* (2)

Pumpkin seed *(Lepomis gibbosus)* (5)

Amphibians

Bull frogs *(Rana catesbeiana)* (6+)

Insects

Damsel fly larvae (6+)

Northern bluet *(Enallagma cynthigerum)* (1)

Spring Pond/Babbling Brook /Nickerson Hill

Fish

Three-spine stickleback *(Gasterosteus aculeatus*) (2)

Amphibians

Bull frogs *(Rana catesbeiana)* (4)

Insects

Northern bluet *(Enallagma cynthigerum)* (1)

Mammals

Eastern chipmunk *(Tamias striatus)* (6+)

Eastern cottontail *(Sylvilagus floridanus)* (1)

Eastern grey squirrel *(Sciurus carolinensis*) (6+)

Birds

Least flycatcher *(Emphidonax minimus*) (2)

Northern cardinal *(Cardinalis cardinalis)* (6)

Red-eyed vireo *(Vireo olivaceus)* (1)

Tufted titmouse *(Baeolophus bicolor)* (3)

Yellow warbler *(Dendroica petechia)* (3)

Willow Pond

Fish

Three-spine stickleback *(Gasterosteus aculeatus*) (1)

Leverett Pond

Fish

American eel *(Anguilla rostrata)* (3)

Bluegill *(Lepomis macrochirus)* (6+)

Goldfish *(Carassius spp.)* (5)

Large mouth bass *(Micropterus salmoides)* (2)

Golden shiner *(Notemigonus crysoleucas)* (6+)

Pickerel *(Esox spp.)* (4)

Pumpkin seed *(Lepomis gibbosus)* (6+)

Yellow perch *(Perca falvescens)* (4)

Reptiles

Painted turtle *(Chrysemys picta)* (6)

Snapping turtle *(Chelydra serepentina)* (1)

Birds

American Crow *(Corvus brachyrhynchos)* 6+)

American Goldfinch *(Carduelis tristis)* (3)

American Robin *(Turdus migratorius)* (3)

Baltimore Oriole *(Icterus galbula)* (1)

Canada Goose *(Branta canadensis)* (6+)

Cedar Waxwing *(Bombycilla cedrorum)* (3)

Common Grackle *(Quiscalus quiscula)* (4)

Double-crested coromorant *(Phalacrocorax auritus)* (3)

Eastern Kingbird *(Tyrannus tyrannus)* (3)

English Sparrow *(Passer domesticus)* (6+)

European Starling *(Sturnus vulgaris)* (6+)

Gray Catbird *(Dumetella carolinensis)* (5)

Herring Gull *(Laurs argentatus)* (6+)

Mallard *(Anas platyrhynchos)* (6+)

Mourning Dove *(Zenaida macroura)* (6)

Northern Cardinal *(Cardinalis cardinalis)* (5)

Northern Mockingbird *(Mimus polyglottos)* (5)

Pigeons *(Columba spp.)* (6+)

Red-winged Blackbird *(Agelaius phoeniceus)* (6+)

Tree Swallow *(Tachycineta bicolor)* (3)

RIVERWAY

Birds

American Crow *(Corvus brachyrhynchos)* (6+)
American Robin *(Turdus migratorius)* (6+)
Black and White Warbler *(Mniotilta varia)* (1)
Blue Jay *(Cyanocitta cristata)* (3)
Canada Goose *(Branta canadensis)* (6+)
Common Grackle (*Quiscalus quiscula)* (6+)
Downy Woodpecker *(Picoides pubescens)* (2)
English Sparrow *(Passer domesticus)* (6+)
European Starling *(Sturnus vulgaris)* (6+)
Mallard *(Anas platyrhynchos)* (6+)
Mourning Dove *(Zenaida macroura)* (6+)
Red-winged Blackbird (Agelaius phoeniceus) (6+)
Northern Cardinal *(Cardinalis cardinalis)* (3)
Rock Dove *(Columba livia)* (6+)
Wood Duck *(Aix sponsa)* (1)

BACK BAY FENS

Fish

American eel *(Anguilla rostrata)* (3)
Bluegill *(Lepomis macrochirus)* (6+)
Common carp *(Cyprinus carpio)* (6+)
Goldfish *(Carassius spp.)* (6+)
Large mouth bass *(Micropterus salmoides)* (2)
Golden shiner *(Notemigonus crysoleucas)* (6+)
Pumpkin seed *(Lepomis gibbosus)* (6+)
Yellow perch *(Perca falvescens)* (6+)

Reptiles

Painted Turtle *(Chrysemys picta)* (4)
Pond Slider *(Chrysemys scripta)* (2)

Birds

American Crow *(Corvus brachyrhynchos)* (6+)
American Robin *(Turdus migratorius)* (6+)
Black-capped Chickadee *(Parus atricapillus)* (6+)
Black and White Warbler *(Mniotilta varia)* (1)
Blue Jay *(Cyanocitta cristata)* (6+)
Common Grackle *(Quiscalus quiscula)* (6+)
European Starling *(Sturnus vulgaris)* (6+)
Gray Catbird *(Dumetella carolinensis)* (6+)
Great Blue Heron *(Ardea herodias)* (1)
Green Heron *(Butorides v. virescens)* (1)
Herring Gull *(Laurs argentatus)* (6+)
English Sparrow *(Passer domesticus)* (6+)
Mallard *(Anas platyrhynchos)* (6+)
Mourning Dove *(Zenaida macroura)* (6+)
Red-winged Blackbird *(Agelaius phoeniceus)* (6+)
Rock Dove *(Columba livia*) (6+)
Song Sparrow *(Melospiza melodia)* (3)
Tree Swallow *(Tachycineta bicolor)* (1)
Tufted Titmouse (*Parus bicolor)* (1)
Yellow Throated Warbler *(Dendroica dominica)* (1)

Appendix E

APPENDIX E

ADDITIONAL MUDDY RIVER HYDRAULIC ANALYSIS

Appendix E
Additional Muddy River Hydraulic Analysis

This memo provides a summary of additional work performed by Camp Dresser & McKee to study the hydraulic conditions of the Muddy River during flood events. This additional work expands upon the modeling efforts described in the following two previous reports:

- **Proposed Phase I Flow Improvements in the Muddy River**
  Prepared for the Executive Office of Environmental Affairs (EOEA) by CDM
  October 1998

- **Hydraulic Modeling, Sediment Quantity and Sediment Quality Issues on the Muddy River**
  Prepared for the United States Army Corps of Engineers, New England District
  September 2000

The hydraulic model for the Muddy River was developed as part of the EOEA report and was a planning level report to identify the potential solutions to the flooding situation. Those solutions and costs have been superceded by subsequent work with the model so the report has not been included in this appendix. Figure 3 from the report is included at the end of this section as a reference to the results of the modeling in the EOEA report.

Hydraulic analysis shown on Figure 3 from the EOEA report indicates that the proposed improvements reduce the flood elevation in the design storm by over 4 feet in the Riverway and Leverett Pond areas. In the Back Bay Fens and Charlesgate areas the improvements are about 1 foot. The reduced flood elevations during the design storm are due to the recommended improvements in infrastructure (culverts and bridges) and limited dredging along the river that caused a major portion of the flooding. Further reduction in the expected flood level is not possible unless a major channel reconfiguration is conducted. The selected design storm of October 1996 resulted in the second highest flood levels in the Muddy River after the hurricane of August 1955. Recommendations in the EOEA report lessened the impacts of the design storm without resorting to major rechannelization. For example, in the Riverway area the berm along the Green line would have nearly been overtopped without the recommended improvements. Once the improvements are completed a flood of similar magnitude would still overflow the river banks but the berm would now be 4 or 5 feet higher than the flood elevation. Many of the roadways that were overtopped (The Riverway near the former Sears parking lot) in 1996 or nearly overtopped (Route 9) would now have significant freeboard and most would no longer be overtopped.

Additional hydraulic analysis described in this section updates the improvements recommended in the EOEA report to reflect further design analysis of the culvert and daylighting improvements.

The Army Corps report (September 2000) is included in this appendix (only sections pertaining to hydraulic analysis) to document the flood conditions in the Stony Brook Conduit and the re-sedimentation conditions. The information was also used to predict velocities in the river as discussed in the Volume 1 of this report.

Objective

The additional analysis is based upon the original set of improvements described in the EOEA and Army Corps reports, and was performed to further support the preliminary design of the improvements proposed in those reports. The analysis incorporated a more detailed simulation of proposed culverts and dredging scenarios which would increase the capacity of the river and reduce the hydraulic grade line (HGL), or water level, observed during storm events.

While the original reports include analyses on a range of design storm events, the additional analysis focused mainly on the improvements predicted for the October 1996 storm. Section 2.2 in the Army Corps (September 2000) report presents a more detailed discussion of the design storms simulated. The real storms chosen are based on the historical precipitation record at Boston Logan Airport, and reflects an additional 35 years of data that has accumulated since the publication of TP-40 (National Weather Service, 1960).

Description

To achieve the desired result of increasing capacity in the Muddy River and reducing the flood levels observed during storms, the original set of improvements proposed in the EOEA and Army Corps reports included dredging portions of the river downstream of the Riverway, and culvert replacement for several locations. To summarize, the original reports proposed the following:

- **Dredging**
  - Removing debris and sediment in the Charlesgate area (between Ipswich Street and the Charles River) which would aim to restore the river bed elevation to about 1.0 ft Boston City Base (BCB) datum. The model simulates the dredged channels with a 30-foot bottom width and about 2:1 side slopes.
  - Removing debris and sediment in the Back Bay Fens (mainly between Boston Gatehouse No. 1 and Ipswich Street), which would aim to restore the river bed elevation to about 1.6 ft (BCB) throughout this reach. The model simulates the dredged channels with a 30-foot bottom width and about 2:1 side slopes.

- **Culvert and Other Improvements**

  - Replace culverts between the Riverway and Brookline Avenue Gatehouse (adjacent to the former Sears parking lot) with twin 10'x10' box culverts.

  - Replace culverts between Brookline Avenue Gatehouse and Upper Fens Pond with twin 10'x'10' box culverts.

  - Replace culverts from Upper Fens Pond to Back Bay Fens with twin 10'x10' box culverts.

  - Daylight the Muddy River at the old Sears parking lot (between the Riverway and Brookline Avenue Gatehouse).

  - Daylight the Muddy River between the Upper Fens Pond and the Back Bay Fens (just upstream of the bridge at Louis Pasteur).

These proposed conditions were simulated with the hydraulic model (SWMM) to evaluate the hydraulic benefit resulting from the increased capacity, and the results are included in the two reports. The original set of improvements was based on hydraulic requirements needed to reduce flood conditions, and did not focus significantly on the actual design which would incorporate a more detailed presentation of improvements.

In an effort to reduce costs and to maintain the aesthetic requirements desired on the project, the preliminary design in this draft EIR expands on the original set of improvements while maintaining hydraulic requirements such as overall culvert cross-sectional area, bed elevation, etc.

The original modeling effort did not explicitly simulate the daylighting at the Sears parking lot and between Upper Fens Pond and Back Bay Fens. These areas were simulated with the proposed twin 10'x10' box culverts, with the intention that the capacity of these culverts is not limiting the limiting factor. Additionally, all proposed culverts were described as 10'x10' box culverts. The original model also did not explicitly simulate the bridge at Louis Pasteur but instead simulated the flow here with the 10'x10' box culvert for the proposed conditions. The bridge was not originally modeled because the twin 72" culverts conveying flow to the bridge from the Upper Fens Pond was limiting flow, and had less cross-sectional area the bridge opening itself.

The following summarizes the changes made to the hydraulic model to simulate the details of the proposed preliminary design:

- Simulate daylighting at the former Sears parking lot and between Upper Fens Pond and Back Bay Fens with open channels having 2:1 to 3:1 side slopes. The daylighting at Sears parking lot was simulated to have a bottom width of about 45 feet, and about 30 feet in the area between Upper Fens and Back Bay Fens.

- In place of the twin 10′x10′ box culverts under the Riverway (at the former Sears lot), simulate a new 10′x16′ arched culvert in addition to the existing twin 72″ drains. The new culvert and existing drains are simulated to run only under the Riverway and drain into the newly simulated daylighting at the former Sears lot.

- In place of the twin 10′x10′ box culverts between the Brookline Avenue Gatehouse and the Upper Fens Pond, simulate a new 10′x24′ arched culvert. Also, leave the existing 7′x9′ and twin 72″ in place between the gatehouse and the Upper Fens Pond, which now simulates the overflow from the Muddy River into the Muddy River Conduit.

- Simulate the 16.5′ wide bridge at Louis Pasteur explicitly. The new analysis simulates daylighting between Upper Fens Pond down to the bridge at Louis Pasteur, whereas the original modeling effort simulated twin 10′x10′ culverts running between Upper Fens Pond, through the bridge at Louis Pasteur, and into the upstream end of the Back Bay Fens.

- Simulate the proposed connection of the Emmanuel College and Brookline Avenue drains directly into the newly proposed 10′x24′ arched culvert in the Muddy River between the Brookline Avenue Gatehouse and Upper Fens Pond. Both drains are part of Boston Water & Sewer Commission facilities. Under the existing condition, the 45″ and 51″x51″ drains cross directly through the 7′x9′ conduit coming out of the Brookline Avenue Gatehouse and eventually discharge into the Muddy River Conduit. Allowing these drains to discharge at this location would increase flow in the Muddy River by about 45 cfs and would reduce flow in the Muddy River Conduit by a like amount.

- Simulate a tailwater at the downstream end of the Muddy River (Charles River) at an elevation of 8.5 ft BCB. This elevation was judged to be the most representative of the likely tailwater for the design storms. A comparison of model results for the October 1996 calibration storm shows a negligible difference in the Muddy River flood levels between a tailwater of 8.0 ft (previously simulated) and 8.5 ft. This would also be expected if the MDC lowered the Charles River so the tailwater was at 7.5 feet as some have suggested.

The areas proposed for dredging in Charlesgate and Back Bay Fens are still simulated with a channel of about 30-foot bottom width with 2:1 side slopes. This channel shape is sufficient to pass the design flow observed during the October 1996.

Results of the Additional Analysis

As the EOEA and Army Corps reports indicate, much of the flooding on the Muddy River can be relieved with the replacement of critical culverts and dredging primarily located downstream in the Charlesgate area and in Back Bay Fens. While the very flat nature of the Muddy River only exacerbates the current flooding situation, it also allows for those improvements initiated downstream to have a significant benefit to upstream flooding.

The relatively flat profile of the river is evident by noting that the normal or dry-weather water surface elevation of the Muddy River is almost flat, with the level at Leverett Pond being similar to the level at the mouth of the Muddy, or the Charles River (see Figure 3 from EOEA report at end of this Section). During storm conditions, improvements made downstream, such as dredging in the Charlesgate and Back Bay Fens areas and culvert replacement under The Riverway (road), Brookline Avenue, and at Louis Pasteur, help to reduce the water levels all the way up through the Riverway and into Leverett Pond. The Riverway is especially flat, and any effort to reduce flooding upstream of The Riverway (road) at the former Sears parking lot is achieved from improving the hydraulic constraints downstream of The Riverway.

Figure E-1 shows the results of the model simulation that represents the preliminary design of proposed improvements. The results are shown for the October 1996 storm. The figure includes a profile of the Muddy River with proposed bottom elevations and hydraulic grade lines, or water elevations, for both the original modeling effort and the additional effort that represents the preliminary design of improvements.

Further model simulations indicate that closing off all overflow (gate and overflow weir at Brookline Avenue Gatehouse) from the Muddy River to the Muddy River Conduit during the October 1996 storm would prevent about 136 cfs from leaving the Muddy River. This does cause an increase in the maximum water level predicted throughout Back Bay Fens and the downstream end of the Riverway by as much as 1 foot, under the preliminary design conditions.

The water levels are dramatically reduced in the flood-prone Riverway for both the original set of improvements (10′x10′ box culverts) and for the improvements simulated under the additional analysis. Further, the more detailed simulation of the preliminary design of culverts and dredging indicates that there is additional hydraulic improvement in the area of the Brookline Avenue Gatehouse. This helps to reduce the water level in the Riverway predicted during the October 1996 storm by as much as 0.3 to 0.6 feet when compared to the original set of improvements simulated for the EOEA and Army Corps reports.

Overall, the additional analysis shows results consistent with the simulation and analysis of the original improvements contained in previous reports.

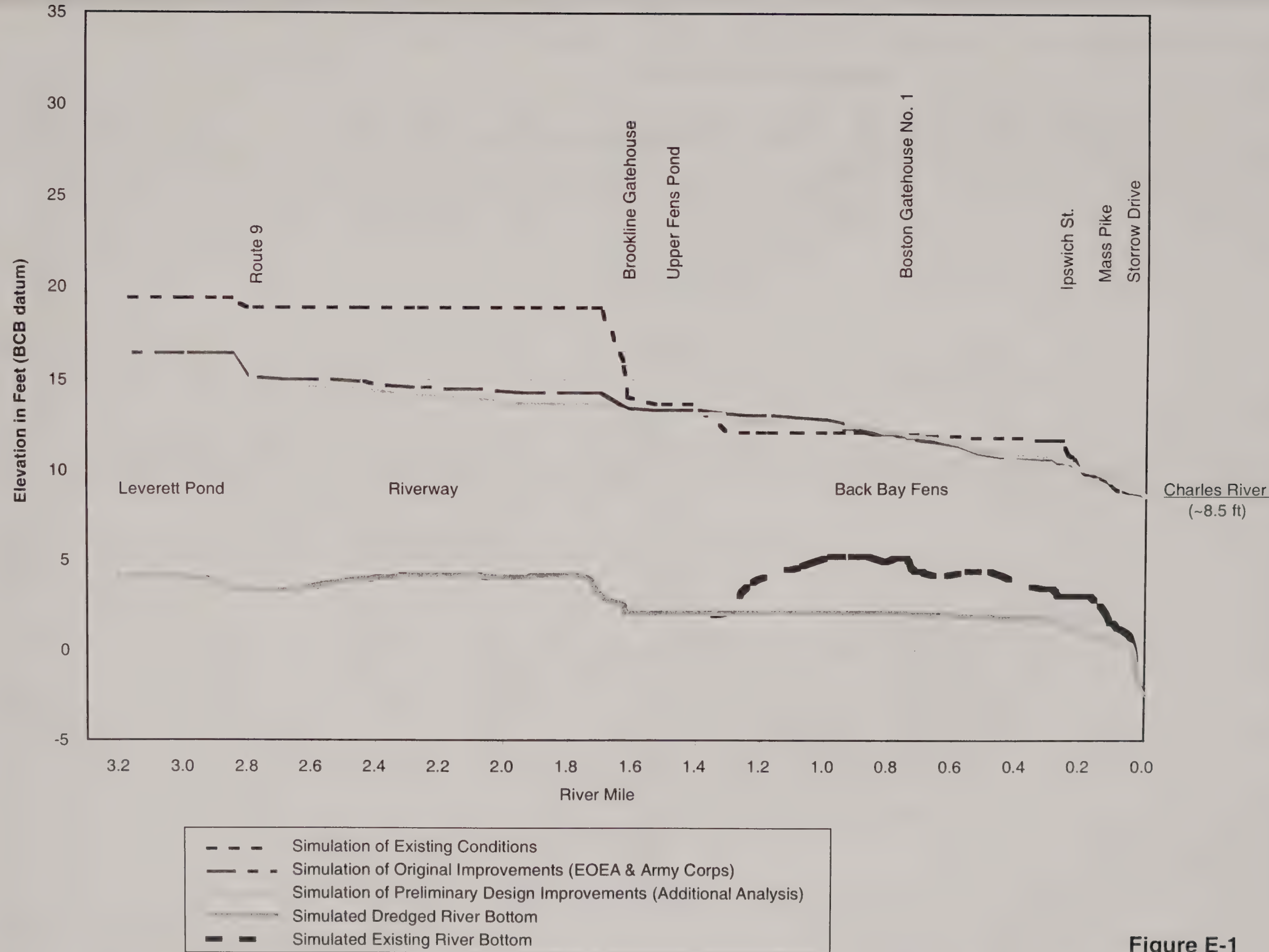
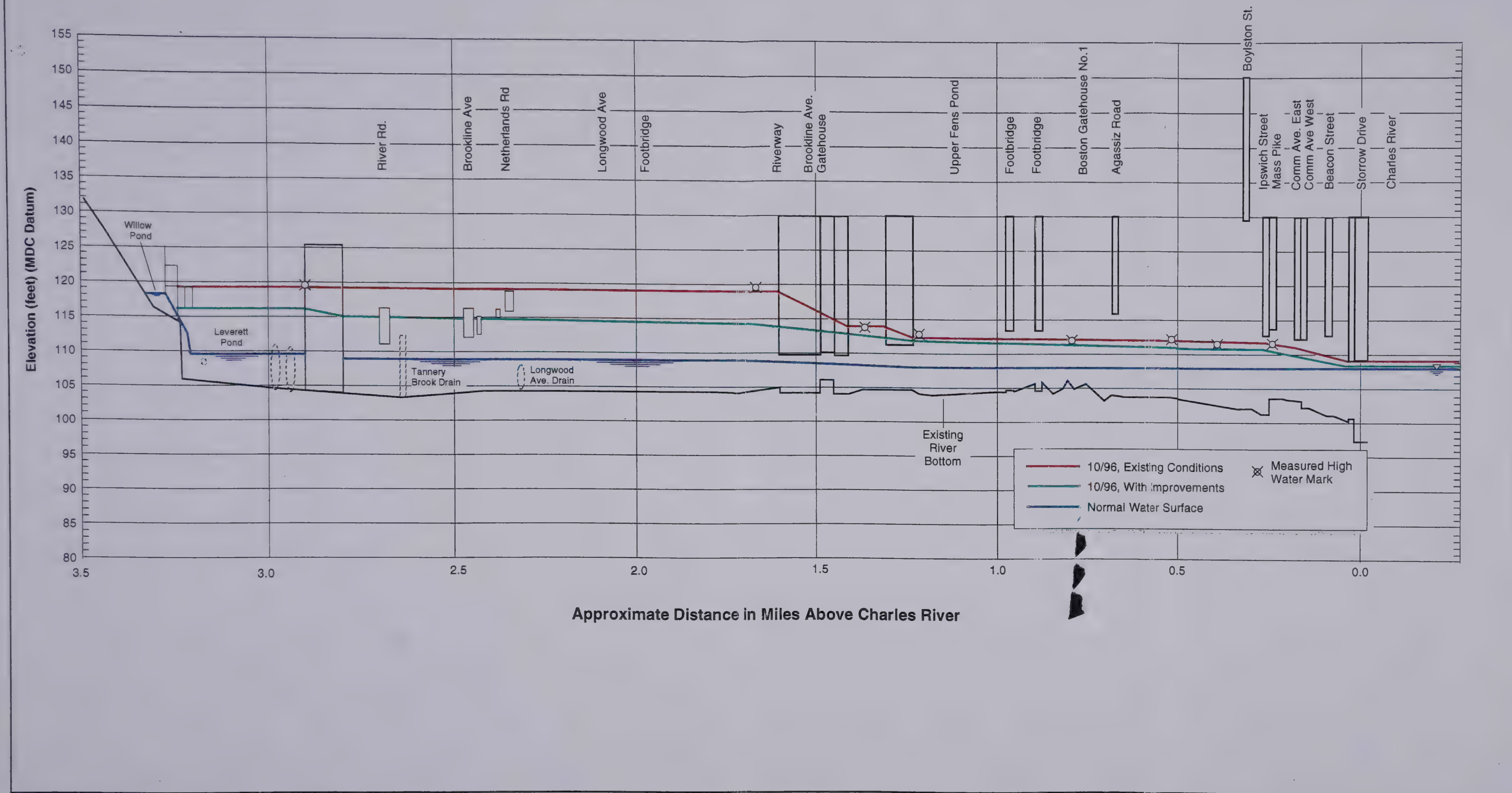


Figure E-1
Peak Hydraulic Grade Lines for the October 1996 Calibration Storm

CDM Camp Dresser & McKee Inc.



Massachusetts Executive Office of Environmental Affairs

Figure 3
Muddy River Water Surface Elevations for Normal and October 1996 Conditions With and Without Phase I Proposed Improvements

CDM Camp Dresser & McKee

United States Army Corps of Engineers
New England District

Hydraulic Modeling, Sediment Quantity and Sediment Quality Issues on the Muddy River

September, 2000

Report

CDM Camp Dresser & McKee Inc.

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Mr. Richard Heidebrecht
U.S. Army Corps of Engineers
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Concord, MA 01742-2751

September 1, 2000

Dear Mr. Heidebrecht,

We are pleased to present you with the final report on Hydraulic Modeling, Sediment Quantity and Sediment Quality Issues on the Muddy River. We have addressed the questions and final report requirements in the memo sent to us as itemized below.

General

- Purpose of study – Page 1
- Listing of reference reports used – Page 1

Hydrology

- Source of rainfall data, discussion on validity of the data - CDM used a combination of real storms (precipitation from Logan airport) and synthetic storms, Page 3 provides a complete discussion
- Method used to develop or assign frequency to storm events, comparison with TP40 – Page 3
- Tabular display of selected rainfall for various storm events – Table 2-1, Page 3

Hydraulics

- Discuss source of data and any critical assumptions used in model – Pages 2-3
- Disk including input and output files for the 10-year event, includes files for existing conditions as well as 30-ft channel and bank to bank dredging proposed conditions
- Inflow hydrographs for all sources – Appendix A
- Outflow hydrographs at three locations for existing and recommended conditions – Appendix B
- Tabular display of previously presented water elevations, profile showing location of elevations – Figures 2-1 to 2-7

Sediment Quality

- Discuss purpose of providing sediment analysis – Pages 6
- Provide method used to calculate sediment loading and reports used for data – Pages 6-9
- Discuss critical assumptions used in analysis – Pages 9-10
- Summary and Conclusions – Page 17

Please feel free to call David Noonan or me if you have any further questions.

Sincerely,

Brent McCarthy

Brent A. McCarthy, P.E.
Camp Dresser and McKee Inc.

cc: Pat Reidy, David Noonan

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1.0 Introduction

Numerous water resource problems exist in the Muddy River Basin near Boston and Brookline, Massachusetts. Large storms have occurred in the Boston area in recent years, resulting in significant flood damage. Interest in restoring degraded ecosystems, as well as alleviating the potential for future flooding problems has resulted in numerous studies involving the Muddy River. This report was prepared for the Corps of Engineers as supporting documentation for the Phase I Muddy River Master Plan. It summarizes the results of three separate analyses, which have implications for flood control as well as improvement of water quality and aquatic habitat.

2.0 Hydraulic Modeling of the Muddy River and Stony Brook Conduit

This section summarizes the results of hydrologic/hydraulic modeling of the Muddy River, as described in U.S. Army Corps of Engineers (COE) revised scope of work, including the optional task described in item b.2. of the scope of work.

Since 1996, several studies have been conducted addressing flooding issues in both the Muddy River watershed and in the Stony Brook Conduit (SBC). A physical description of the study area, the model, and details on past work are not described in this memo, but can be found in various reports, including the following:

- Submitted to the Chief of Engineers. 1966. Reconnaissance Report – Local Protection, Muddy River, Boston-Brookline, Massachusetts
- USACE. 1968. Charles River Interim Report – Lower Charles River.
- USACE. 1972. Charles River Study Report.
- USACE. 1992. Water Resources Study. Muddy River Watershed
- USACE. 1996. Muddy River Flood Analysis
- USACE. 1998. Draft Feasibility Report and Environmental Assessment, Muddy River Feasibility Study, Boston and Brookline, Massachusetts
- CDM. 1998. Hydraulic Modeling of the Stony Brook System

2.1 Purpose and Scope

This work involved simulating the hydraulic conditions of the Muddy River and the Stony Brook Conduit for three design storms designated by USACE. An existing computer model was used for the simulations. The model was used to predict hydraulic conditions for both the Muddy River and SBC for each of the design storms, including peak flood elevations, hydraulic gradelines, and overflow volumes. (Note that all elevations reported in this memo are in reference to the Metropolitan District Commission (MDC) datum.)

The three main elements (excluding the optional task) of the scope of work are:

- Simulate the hydraulic gradeline (HGL) of the Muddy River and Stony Brook Conduit for three different design storms, and for two different physical scenarios (Existing Conditions and Recommended Improvements),

- Estimate the frequency of the storm that causes flooding in the Stony Brook Conduit at Parker Street near Wentworth Institute, and
- Determine the volume and duration of overflows at Parker Street for the various design storms.

The Existing Conditions scenario assumes that all four gates at Boston Gatehouse No. 1 (BGH#1) are closed, allowing discharge from the SBC to the Muddy River Fens only by way of the overflow weirs. It also assumes that the butterfly gate at Brookline Avenue Gatehouse at Park Drive is open, allowing additional flow to discharge to the Charles River via the Muddy River Conduit.

The Recommended Improvements scenario is essentially the same as Scenario 33 simulated under previous work (CDM, 1998). This scenario includes the following:

- Sediment is removed from the SBC from Tremont Street to BGH#1.
- Sediment is removed from the Foul Flow Conduit (FFC) from BGH#1 to MWRA's Charlesgate East Gatehouse.
- Two of the four gates in BGH#1 are raised by three feet.
- The existing twin 6-foot diameter culverts on the Muddy River between Park Drive and Brookline Avenue Gatehouse are replaced with a 10-foot by 20-foot box culvert.
- The existing 7-foot by 9-foot box culvert and the twin 6-foot diameter culverts on the Muddy River between Brookline Avenue Gatehouse and Upper Fens Pond are replaced with a 10-foot by 20-foot box culvert.
- The existing twin 6-foot diameter culverts on the Muddy River between Upper Fens Pond and the Muddy River Fens are replaced with a 10-foot by 20-foot box culvert.
- A 30-foot wide bottom-width channel with 2:1 side slopes is dredged along the Muddy River between BGH#1 and Ipswich Street. The channel is dredged to invert elevation 101.6 feet (MDC datum).
- Sediment is removed from the six bridge openings and the open channel reaches from Ipswich Street to the Charles River.
- The stop log structure located in the Ipswich Street bridge opening is removed.
- Additionally, the butterfly gate in the Brookline Avenue Gatehouse is assumed to be closed, and sediment has not been removed from the Muddy River Conduit. (Note that Scenario 33 (CDM, 1998) assumed sediment removal from the Muddy River Conduit.)

The Bank-to-bank Improvements scenario is the same as for Recommended Improvements, but with expanded dredging of the Muddy River. Dredging is extended across the entire width of the channel, rather than limited to a 30-foot width. Bank-to-bank dredging was simulated in existing open channel reaches between Brookline Avenue Gate and Ipswich Street Bridge, including the Upper Fens Pond. As with the Recommended Improvements scenario, dredging to an invert elevation of 101.6 feet (MDC datum) was simulated, based on a previous design (USACE, 1992). Note that the model requires a slight gradient, so the simulated inverts are slightly higher than 101.6 at the upstream end, and gradually decrease in the downstream direction. To incorporate bank-to-bank dredging into the model, reach dimensions were modified to simulate

trapezoidal channels by extending a 2:1 side slope from the existing tops-of-bank to the required invert.

2.2 Design Storms

Three new design storms were specified in the scope of work, in addition to two storms that were simulated under previous work. The new storm frequencies are 10-year, 25-year and 100-year. The two previous storms were for a 2-year design storm and the calibration storm of October 1996.

The 100-year storm was specified in the scope to be the August 18, 1955 storm. The 10- and 25-year storms were specified to be synthetic storms developed using criteria previously used by CDM. As the work progressed, CDM recommended that actual 10- and 25-year storms be simulated in place of the synthetic storms. Since simulations were completed for both actual and synthetic storms, data for both are presented in this memo. Table 2-1 is a summary of the design storms, including total depth, duration, and peak intensity.

Table 2-1 Description of Design Storms.

Design Storm Frequency	Date	Total Rainfall Depth, inches	Duration, Hours	Peak hourly Intensity, inches
2-Year	9/11/60	3.28	29	1.03
10-Year	Synthetic	4.81	24	1.60
10-Year	10/13/90	3.91	23	0.93
25-Year	Synthetic	6.17	24	1.95
25-Year	5/15/54	5.74	18	0.98
100-Year	8/18/55	11.93	39	1.41
Calibration Storm	10/20/96	7.90	37	0.63

The actual rainfall data was taken from the historical precipitation record for Logan Airport. A complete analysis on how this historical precipitation compares to rainfall depths established by the National Weather Service in its 1960 TP-40 publication is included in CDM's 1998 report on the Hydraulic Modeling of the Stony Brook System. For most of the storm durations and frequencies the Boston rainfall data differs from TP-40 by 10 percent or less. However, for durations from 6 to 24 hours and return periods of 25 to 100 years the updated values exceed the TP-40 values by 15 percent or more. This is a reflection of the more than 35 years of data that have accumulated since the publication of TP-40.

2.3 Model Description

An existing hydrologic/hydraulic model of the Muddy River and Stony Brook systems was used for these analyses. CDM (1998) prepared the calibrated model in its current form, and developed the model based on a previous model (COE, 1996). The existing model is an EPA SWMM model. Hydrology of the Muddy River and Stony Brook watersheds was simulated using the RUNOFF block of SWMM. The EXTRAN block of SWMM was used to simulate hydraulics in the open channels, bridges, culverts, and pipes of the Muddy River/Stony Brook systems. The RUNOFF model generates inflow hydrographs to be used as input for the EXTRAN model.

Minor modifications were made to the existing model, mainly by extending the overbanks of open channel reaches of the Muddy River to ensure that larger storms would be adequately simulated. Another modification was to use a constant tailwater in the Charles River of 108.5 feet, slightly higher than the constant tailwater of 108 feet that was used previously. An elevation of 108.5 feet was judged to be the most representative of the likely tailwater for the design storms. A comparison of model results for the October 1996 calibration storm shows a negligible difference in Muddy River flood levels between the two different tailwater elevations. Following these modifications, the model calibration was checked and found to be consistent with previous simulations.

2.4 Peak Hydraulic Gradelines

Table 2-2 is a summary of peak HGL elevations at key locations in the Muddy River/Stony Brook system. The key locations are described as follows:

Muddy River

- Muddy River Fens near BGH#1 – BGH#1 is the hydraulic link between SBC and the Muddy River.
- Riverway – In the Muddy River just upstream of Park Drive, and just upstream of the culverts leading to Brookline Avenue Gatehouse.
- Upstream end of the Muddy River Conduit – just downstream of the Brookline Gatehouse.

Stony Brook Conduit

- BGH#1 – In the gatehouse on the Stony Brook side of the gates.
- Parker Street near Wentworth Institute – This is the location of significant street flooding. The rim elevation for controlling manhole is 117.2 feet (MDC datum).
- Archdale Street – In the Stony Brook Conduit upstream of Parker Street, near the location of an existing MWRA combined sewer overflow to the SBC.

Figures 2-1 through 2-7 show peak HGLs along the Muddy River, from the Charles River to Leverett Pond. The information presented in the figures is outlined below:

- Figure 2-1 – Peak HGLs for the four design storms and the calibration storm for existing conditions. (Synthetic design storms are not included.)
- Figure 2-2 - Peak HGLs for the four design storms and the calibration storm for recommended improvements. (Synthetic design storms are not included.)
- Figure 2-3 – Peak HGL for the 2-year storm for existing and improved conditions.
- Figure 2-4 – Peak HGL for the 10-year "actual" design storm for existing and improved conditions. (The synthetic design storm was not plotted).
- Figure 2-5 – Peak HGL for the 25-year "actual" design storm for existing and improved conditions. (The synthetic design storm was not plotted).
- Figure 2-6 – Peak HGL for the 100-year storm for existing and improved conditions.
- Figure 2-7 – Peak HGL for the October 1996 calibration storm for existing and improved conditions.

Note that the HGLs in Figures 2-1 through 2-7 do not necessarily represent a single point in time. Instead, they represent the peak water elevation at each junction in the model, regardless of time of occurrence. Since EXTRAN is a dynamic model, and the hydraulics of the Muddy River/Stony Brook systems are complex, peak flows and peak flood levels are not likely to occur simultaneously throughout the system.

2.5 Flooding Frequency at Parker Street

The storm frequency that causes flooding at Parker Street was estimated by assuming that a log-normal distribution exists for storm probability versus HGL. The probability of a given design storm occurring in a given year was assumed to be a simple ratio relative to the return period (i.e., a 10-year storm has a probability of 0.1, a 25-year storm has a probability of 0.04, and so forth).

Figure 2-8 shows the log-normal relationship between storm probability and HGL at Parker Street for the four design storms. Both the "existing conditions" and the "recommended improvements" scenarios are shown, along with trendlines. The correlation coefficient (R-squared) was greater that 0.9 for each trendline.

For existing conditions, the data suggest that the HGL reaches street level on an annual basis. With recommended improvements in place, a storm with a return period of approximately 10 years can be expected to cause severe surcharging and possible street flooding at Parker Street.

2.6 Flooding Volume and Duration at Parker Street

Table 2-3 shows the predicted peak flood elevations, overflow volumes, and duration of street flooding at Parker Street for the various storms. The data in Table 2-3 are for existing conditions and for the recommended improvements.

The estimates of street flooding duration include the entire time that the HGL is above the rim elevation of 117.2 feet. It includes the amount of time that water discharges from the SBC system, and the amount of time required for ponded water to re-enter the system. The exception to this is for the 100-year design storm under existing conditions. For this simulation, the flooding duration of 40 hours includes nine hours between two distinct flooding periods when the HGL was below elevation 117.2 feet.

3.0 Sediment Quantity

3.1 Purpose and Scope

The purpose of the investigation presented in this section is to quantify the amount of time it takes for sediment in the Muddy River to re-accumulate to existing conditions, after the proposed dredging of the Muddy River Restoration project is completed. This analysis provides estimates of the depth of accumulation of sediment, as well as the total sediment volume, in three areas of the Muddy River; Leverett Pond, the Riverway and the Back Bay Fens. The estimates of sediment depth are for time periods of 5, 10, 20, and 30 years after the proposed dredging has taken place. Factors taken into consideration in this analysis include stream geometry and suspended solids loading data, which is based on land use.

3.2 Data

Data used to determine the volume and depth of sediment in the Muddy River were taken from various sources. The stream geometry data is from a SWMM Model of the Muddy River (CDM, 1997). This cross-section data is originally from the Corps' UNET model of the Muddy River. To model improved conditions of the Muddy River assuming dredging has occurred, existing sediment depths were subtracted from the stream bed of the existing cross-section data. Existing sediment depths for each cross-section were determined using measured sediment depths from the USGS (1997). The resulting cross-sections are representative of the improved conditions in the stream, which would result from the proposed dredging.

Annual total suspended solids loads were determined using NURP national average data and a methodology from CDM's Watershed Management Model (WMM) as described below (CDM, 1992).

3.3 Methods of Analysis

A spreadsheet analysis was used to determine the depth of sediment accumulation in three areas of the Muddy River: Leverett Pond, the Riverway, and the Back Bay Fens.

3.3.1 Existing sediment volumes

In order to estimate existing sediment volumes in Leverett Pond, the Riverway, and the Back Bay Fens, each area was separated into smaller areas that have similar characteristics, for a total of nine subareas in the study area. Figure 3-1 is a map of the study area showing the location of

the nine subareas. An average cross-section was then determined for each of the nine subareas. This was achieved by plotting each of the cross sections in the reach and determining the average width to which existing sediment occupies the cross-section. The length of the characteristic reach was determined by summing all the lengths of the SWMM model cross-sections included in that representative reach.

The sediment depth was estimated using 1997 USGS data on sediment depths for the entire Muddy River. For each representative reach as described above, an average sediment depth was determined using the USGS data. The existing sediment volume was then computed based on the reach length, estimated average cross-sectional width, and the estimated average sediment depth. The existing sediment volumes were then summed and the total sediment volume was used along with the sediment volume for each reach to determine the distribution of existing sediment volume throughout each of the three areas, Leverett Pond, the Riverway, and the Back Bay Fens.

It was assumed that post-dredging conditions would be similar to pre-dredging conditions in that the sediment would tend to be deposited in the same areas as in the past (i.e. based on velocity and river configuration). For this reason, the percentage of the total volume of sediment for each area remains the same for existing sediment volumes as for the sediment volumes estimated in this analysis.

3.3.2 Event Mean Concentrations and Total Suspended Solids Loads

Total suspended solids (TSS) loads were estimated using event mean concentrations described in WMM. Event mean concentrations (EMCs) were estimated for numerous pollutants in the national NURP data. The EMCs used in this analysis were from the national data, although Eastern Massachusetts data shows SMCs (sample mean concentrations) tend to be lower than the national average. For instance, SMC's from wet weather sampling in West Roxbury range from 10 to 92 mg/L (BWSC, 1998). Yearly loads calculated using the national NURP average are slightly higher and therefore more conservative when used to estimate sediment depths compared to depths calculated using Boston specific data. Event mean concentrations (EMCs) were obtained directly from WMM. Table 3-1 shows the mean EMCs associated with each land use in the study area. Table 3-2 shows the comparison between national average EMCs and Boston area SMCs.

Event mean concentrations (EMCs) of total suspended solids were obtained from CDM's Watershed Management Model (WMM) and used to determine the annual load of sediment entering the Muddy River. Total suspended solids concentrations are based on the type of land use, percent imperviousness, and total acres of that land use type in each subbasin. Table 3-1 shows the percent imperviousness and TSS concentration associated with each type of land use.

Table 3-1 Land Uses and Event Mean Concentrations

Land Use	**% Impervious**	**EMC (mg/L)**
Forest/Open	0.5	216
Agriculture/Pasture	0.5	216
Low Density Single Family Residential	10	140
Medium Density Single Family Residential	30	140
High Density Residential	50	140
Commercial	90	91
Heavy Industrial	80	91
Water	100	26
Wetlands	0.5	216
Transportation	90	142

Table 3-2. Sample mean concentrations for West Roxbury, MA

Date	TSS (mg/L) (1)
4-17-92	20
6-1-92	76
6-24-92	24
4-17-97	41
8-13-97	66
8-21-97	12
10-25-97	28
10-27-97	11
11-1-97	37
11-22-97	40
1-7-98	12
1-23-98	25
2-12-98	92
3-19-98	18
Average	39

(1) Concentrations based on flow-weighted composite sample of partial event

To convert event mean concentrations of TSS to annual loads, WMM nonpoint pollution loading factors were used. WMM nonpoint pollution loading factors vary by land use and percent impervious of each land use. For each land use, M_L, the pollution loading factor in pounds per year was calculated using the following equation.

$$M_L = EMC_L * R_L * K * A_L \qquad \text{(Equation 3-1)}$$

where M_L is the loading factor for land use L in pounds per year, EMC_L is the event mean concentration of runoff from land use L in milligrams per liter, A_L is the area of land use L in acres, K is equal to 0.2266, a unit conversion constant, and R_L is the total average annual surface runoff from land use L in inches per year. R_L is computed using equation 3-2, below.

$$R_L = [\ C_p + (C_I - C_p)IMP_L\ ] * I \qquad \text{(Equation 3-2)}$$

where R_L is the total average annual surface runoff from land use L in inches per year, IMP_L is the fractional imperviousness of land use L from Table 3-1, I is the long term average annual precipitation in inches per year, C_p is the pervious area runoff coefficient, 0.20, and C_I is the impervious area runoff coefficient, 0.95. For the Boston area, the long term average annual precipitation is 41 inches per year (NOAA, 2000).

Once annual sediment loads were determined, they were converted to volumes using the bulk density of dry sand, 1.2 g/cm^3. This volume of sediment was then distributed among the nine subareas using the distribution pattern of the existing sediment along with the reach length and average cross-section width for the reach.

3.3.3 Local Inflows and Suspended Solids Loads

Five major inflows contribute 80% of the total suspended solids load to the Muddy River. These include the Chestnut Street Drain, Daisy Field Drain, Village Brook Drain, Tannery Brook Drain and the Longwood Avenue Drain. Fifteen other inflows contribute the remaining 20% of the TSS load to the Muddy River. Table 3-1 gives the annual TSS loads for the five major inflows to the Muddy River. The loads in Table 3-3 were determined using EMC, R_L, and M_L as discussed in the previous section.

The inflow from the Stony Brook Conduit (near the Boston gatehouse) was determined using a different method, because there was no data available in WMM for this conduit. An annual TSS load for the Stony Brook conduit was determined using the following method.
The flow volume for the Stony Brook Conduit for 1-yr 6-hour storm (determined using a SWMM model) was compared to the flow volume for the 1-yr 6-hour storm for Village Brook Drain. Comparing the two flow volumes shows that the flow volume from the Stony Brook Conduit is approximately 55% of the flow volume from Village Brook Drain for the 1-yr 6-hour storm. Therefore, the annual TSS load from the Stony Brook Conduit was also assumed to be 55% of the annual load from the Village Brook Drain. This is based on the assumption that the land use distribution in the two subbasins is very similar.

Table 3-3. Inflow TSS Loads to the Muddy River

Inflow	Annual TSS Load (lbs)
Chestnut St. Drain	79,454
Daisy Field Drain	31,396
Village Brook Drain	1,180,809
Tannery Brook Drain	240,910
Longwood Ave. Drain	132,529
All Other Drains	395,171
Stony Brook Conduit	649.445

4.0 Results and Interpretations

This section discusses the estimated average depth of sediments for each of three areas: Leverett Pond, the Riverway and Back Bay Fens at time intervals of 5, 10, 20 and 30 years after the proposed dredging occurs.

4.1 Base Case

For the base case, which assumes that organic sediment is minimal, the estimated average sediment depth in each of the three areas of the Muddy River is as follows: for Leverett Pond, the estimated average depth of sediment (across the river reach) after 30 years is approximately 0.4 feet. For the Riverway, the estimated average depth of sediment ranges from 0.0 to 0.5 feet, with the highest accumulated depth of sediment downstream of the Longwood Avenue bridge.

The greatest depths of accumulation are predicted to occur in the Back Bay Fens, with estimated average sediment depths of 0.5 to 3 feet. The Back Bay Fens currently has large volumes of sediment which have been deposited in the past 30 years due to sluggish flow in this area and the existence of phragmites, further reducing flow velocities. Table 5-1 lists the estimated average sediment depths in each of the nine areas.

4.2 Additional 25% organic material (Case 2)

The previously described base case estimates of average sediment depth only account for sediment accumulated as a result of the estimated annual TSS loads to the Muddy River. In addition, decaying vegetation and other organic matter are known to contribute significant amounts of sediment to the system. (USACE, 1998). For purposes of this analysis, it is estimated that an additional 25% of sediment is organic in nature. For case 2, this additional 25% of organic material is added to the volume of sediment and distributed throughout the 9 reaches used in this analysis. Because organic sediments are typically less dense than their inorganic counterparts, the same amount of organic mass occupies a greater volume than that of inorganic sediments. A density of 0.9 g/cm^3 was used as the density of organic sediment for purposes of this analysis.

Table 5-1 shows that for Case 2, the estimated depth of sediment accumulated after 30 years ranges from 0.5 ft in Leverett Pond to 4 feet in the Fens area.

4.3 BMPs – 30% removal efficiency (Case 3)

Improvements to the storm drainage systems in the Muddy River basin were also taken into consideration (i.e. sediment traps in the Tannery Brook Drain). A 30% removal efficiency was assumed for this part of the analysis, resulting in a 30% reduction in the total suspended solids loading to the Muddy River. This results in a 30% reduction in the average sediment depths compared with the depths from Case 2, which accounts for organic material in the sediment. The estimated sediment depths for each of the time periods with BMP's in place are included in Table 5-1.

5.0 Conclusion

The estimated average sediment depths are the depths of accumulated sediment based on the average cross-sectional width for that particular reach. Actual cross-sections within a reach can be narrower or wider; and sediment depths can be higher or lower than the estimated average depth for that reach (possibly half to twice as deep). These average sediment depths should be recognized as estimates only and are more useful in helping to determine average volumes in generalized areas than actual depths at specific cross-sections.

One of the primary objectives of this analysis is to determine the amount of time it will take for sediment to re-accumulate to existing depths in the Muddy River. As Table 5-1 shows, if best management practices are in place, the estimated average sediment depths in each of the nine subareas are less than the average existing depths for time periods of 30 and 50 years. This is true in all subareas except for subarea nine, where after 30 years, the sediment depth is slightly greater than the existing depth (2.7 feet versus 2.5 feet). The results of this analysis show that with best management practices in place, sediment depths will not reach existing depths for 50 years or more, except in the most downstream areas.

Table 5-1. Comparison of average existing sediment depths with estimated sediment depths.

		With BMPs		Without BMPs	
No.	Avg. Existing depth, ft (1)	30-year depth, ft	50-year depth, ft	30-year depth, ft	50-year depth, ft
1	2.5	0.35	0.58	0.52	0.87
2	3.3	0.42	0.7	0.63	1.1
3	4.1	0.48	0.8	0.73	1.2
4	0.5	0.06	0.1	0.09	0.15
5	3.3	0.51	0.84	0.76	1.3
6	4.9	0.58	0.96	0.87	1.5
7	6.6	1.1	1.9	1.7	2.9
8	4.9	0.98	1.6	1.5	2.5
9	2.5	2.7	4.5	4	6.7

(1) Estimated using USGS (1997) data.

6.0 References

Boston Water and Sewer Commission, "Residential Stormwater Monitoring Project Summary Report," June, 1998.

Camp Dresser and McKee. "Technical Memorandum Number 1: Preliminary Assessment of Muddy River Capacity and Selection of Storm Events." December, 1997.

Camp Dresser and McKee, Inc. "Watershed Management Model: WMM/NPDES, User's Manual Version 3.10." 1992.

National Weather Service. www.nws.noaa.gov/er/box/climate/BOSTON_MA___.html

United States Army Corps of Engineers. "Muddy River Feasibility Study, Draft Feasibility Report and Environmental Assessment," February, 1998.

United States Geological Survey. "Channel Morphology and Streambed-Sediment Quality in the Muddy River, Boston and Brookline, Massachusetts." October, 1997.

7.0 Sediment Quality

7.1 Sources

The sources of sediment contamination include point and non-point source pollution. Point sources in the Muddy River include municipal storm drains and direct runoff swales. Non-point

sources include runoff from roads, parking lots, commercial and business establishments, industries, lawns and parkland, as well as atmospheric deposition.

Two point sources and one non-point source dominate the Muddy River drainage system and consequently, typically contribute the largest volumes of sediment. The Village Brook drain, Tannery Brook drain, and direct non-point source runoff along the edges of the Muddy River account for 76% of the drainage area discharging to the Muddy River. In addition, the Stony Brook Conduit located in the Back Bay is a periodic—but sometimes significant—contributor of sediment to downstream points including the Charlesgate area.

7.2 Existing Sediment Quality

CDM reviewed existing sediment quality data as compiled from NAE in July 1998, Anderson-Nichols "Phase 1 Planning Report on Rehabilitation of the Muddy River Conduit (October 1992), and the USGS's streambed sediment quality report (Water Resources Investigations Report 98-4027). Note that CDM has developed and is implementing a comprehensive sediment characterization plan that will include sediment borings at 140 locations, and sampling and analysis for petroleum hydrocarbons, 8 RCRA metals, pesticides, PCBs, conductance, TCLP metals, reactivity and corrosivity. The intent of this program is to determine disposition requirements (lined landfill versus unlined landfill) in advance of actual dredging. However, this information will not be available in time for this project. In addition, the Corps of Engineers recently completed sediment sampling at Ward's and Willow Ponds.

Existing data show the following contaminants were in elevated concentrations in the three sections of Muddy River included in this project, so that sediment, once dredged, would have to be disposed at a lined landfill:

Leverett Pond: Arsenic, polyaromatic hydrocarbons (PAHs), TPH
The Riverway: PAHs, TPH
Back Bay Fens: Arsenic, lead, PAHs, TPH

Illegal sanitary connections in the Village Brook drain (which discharges to Leverett Pond) have caused elevated levels of coliform in the Muddy River in the past. The Town of Brookline, under an EPA Consent Order, has taken steps to identify, isolate, and remove illegal sanitary connections. Brookline continues to monitor for other illegal connections. Boston, under the terms of its NPDES Stormwater permit, also monitors for illegal connections.

7.3 Future Sediment Quality

Future sediment quality is expected to change for certain contaminants based on changes in activities and procedures regarding source controls. Factors affecting sediment quality include regulatory changes, planned public works projects, and more intensive implementation of best management practices within the watershed. These activities will reduce either the quantity and/or quality of sediment reaching the Muddy River.

Factors that will likely improve sediment quality in the future include:

-Ban on DDT and polychlorinated biphenyls (PCBs). These chemicals were released into the watershed many years ago, but persist for decades because of their chemical composition. The use of both was banned in the 1970s. Concentrations of PCBs in Muddy River sediments have been high in specific areas. Once the Muddy River is dredged, it is expected that future concentrations will be dramatically reduced and eventually become non-detectable.

-Ban on use of leaded gasoline. Lead has been found in elevated concentrations in the Back Bay Fens sediments. One of the primary sources of lead is atmospheric deposition and washoff of leaded gasoline coming from automobiles, trucks, and buses. Banning lead from gasoline reduces a significant source in the watershed. Lead levels in future sediments are expected to decrease in the future.

-Stony Brook Conduit cleaning and lining. The Boston Water and Sewer Commission (BWSC) is undertaking a project to clean the sediment-laden pipelines draining Stony Brook. Pipelines proposed for cleaning include the Stony Brook Conduit, which discharges directly to the Muddy River during heavy rainfalls and has created a sand bar, and the major pipeline in the Stony Brook system from Boston Gate House Number 1 to the Charles River. Removing these sediments from the pipes will improve water quality in the future, especially as it relates to the more persistent and historic compounds like PAHs and metals.

-BWSC Catch Basin Identification and Cleaning Project. Beginning this summer, BWSC will be undertaking a project to identify and inspect all of its catch basins. BWSC believes that there are between 26,000 and 40,000 catch basins in the city. Many need to be located, and subsequently, cleaned. The project, which is expected to take 5 years to implement, is expected to improve future sediment quality for a wide range of parameters including metals, PAHs, nutrients, and TSS.

-Management Plan for the Muddy River Restoration Project. At the end of the restoration project, Boston Department of Parks and Recreation will present a comprehensive Management Plan that addresses the implementation and enforcement of BMPs. The plan will include municipal services (e.g., street sweeping, catch basin cleaning), infrastructure maintenance (e.g., illegal sanitary connection removal, screen and trash rack cleaning), public education (e.g., residential hazardous waste collection, waste oil collection), and regulations (e.g., pooper scooper ordinances, new construction specifications). Full implementation of this plan, assuming proper funding by Boston, Brookline and the MDC, would significantly reduce the amounts of sediment reaching the Muddy River, and improve the quality of any sediment that does remain. As a conservative estimate, CDM has assumed a minimum of a 30% reduction in the volume of sediment reaching the Muddy River annually.

-Brookline Illegal Sanitary Connection Removal Program. The presence of sewage in the Muddy River in the 1990s prompted EPA to issue a consent order to have the Town of Brookline identify and eliminate the source of the problem. Brookline undertook an aggressive program to

locate and remove illegal sanitary connections in its system, particularly in the Village Brook drainage area. The ongoing program has resulted in significant improvement in water quality.

Factors that will continue to degrade sediment quality into the future include:

-Automobiles, buses, trucks. The Muddy River watershed is heavily urbanized. Some of the watersheds draining to the Muddy River are highly impervious due to roadways, parking lots and buildings, including Brookline Village watershed (79% impervious), Pilgrim Road watershed at the Riverway (71% impervious) and Brookline Ave. watershed (65% impervious). Vehicle use is expected to continue at present levels in the foreseeable future. Vehicle parts and fluids (antifreeze, rubber tires, undercoatings, and engine wear) will continue to be sources of lead, cadmium, copper, manganese and nickel. Vehicles will also continue to be a source of oil and grease and TPH in the watershed.

-Naturally occurring vegetation die-off. The Corps of Engineers estimates that the die-off of natural vegetation in the Muddy River could account for as much as 25% of the total sediment loading. Even with proper park management and maintenance, some level of natural sediment must be expected. Because of the capacity for some plants to uptake contaminants in sediment and water ("phytoremediation"), there is likely to be some low levels of contamination in even "natural" sources of sediment.

7.4 Likely Future Concentrations of Specific Contaminants

Table 7-1 presents existing concentrations for those contaminants where data are available. Below is a qualitative discussion of how the concentrations of the contaminants are expected to remain at prior levels or decrease in the future once the existing sediment has been removed.

PCBs

PCBs were banned by the federal government in the 1970s. Consequently, once the existing contaminated sediments have been removed, we expect some minimal level of PCBs to continue to wash off the watershed due to prior accumulations, which tend to persist in the environment due to their molecular structure . As the remaining loadings are flushed out, we expect that the concentrations *will decrease immediately and eventually become non-detectable.*

Metals

Given the urbanized nature of the Muddy River and the prevalence of vehicular traffic throughout the watershed, metals will continue to wash off roadways and settle out in the river. Nevertheless, more aggressive street sweeping and catch basin cleaning will result in the capture of more solids. For this study, we estimate that over the next 30 years, concentrations of metals will *gradually decrease* over time as BMP performance improves *but still remain at detectable concentrations.* Because of the ban on leaded gasoline, we expect that out of all the metals, *lead will show the most dramatic reductions in concentrations over time.*

Nutrients

Nutrient concentrations in sediment are not available. Water quality in the water column shows high levels of nutrients, presumably from fertilizer use, animal wastes, and naturally occurring vegetation die-off.. The natural vegetation die-off and large drainage area that discharges directly to the Muddy River will continue to be a source of nutrients in the future. We estimate that nutrient concentrations (phosphorus and nitrogen compounds) *will gradually decrease over time but remain at detectable levels.*

Note that no widespread algae blooms have occurred in the Muddy River even though phosphorus and nitrogen concentrations are high enough in the water column to create blooms. It is possible that the turbidity levels in the Muddy River prevent enough sunlight from penetrating the water column. Thus, there is a concern that reducing sediment loads to the Muddy River could result in improved turbidity in the river, and possibly result in algae blooms where none have occurred before. If a bloom occurs, it will bring with it the possibility of eutrophication. More aggressive control of nitrogen and phosphorus compounds will then become critical. It will take several years to assess these potential implications of the Muddy River project.

COD, oils and grease, BOD, TSS

No sediment data are available for these compounds. There are a number of BMPs that are planned for the watershed that, if aggressively implemented, will reduce pollutant loadings reaching the river, including: illegal sanitary connections elimination, trash and litter control, goose control, pooper scooper ordinance, waste oil collection program, roadway patching and repair, street sweeping and catch basin cleaning. Sources of these contaminants will continue to exist in the watershed. We expect concentrations to *gradually decline over time but still remain at detectable levels.*

PAHs

PAHs are in high enough concentrations that existing sediment will need to be placed in a lined landfill. Given the urbanization of the Muddy River watershed, PAHs will continue to wash off into the river. Again, with proper BMP implementation, levels can begin to be reduced over time. Because of their chemical structure, PAHs tend to persist in the environment for long periods of time. Thus, we expect concentrations *to gradually decrease over time, but remain at detectable levels.*

Bacteria

Continued aggressive implementation of Brookline's illegal sanitary connection elimination program, combined with aggressive enforcement of the pooper scooper ordinances and geese control programs will result in dramatic reductions and ultimately non-detectable levels of fecal coliform in the watershed.

8.0 Conclusions

8.1 Hydraulic Modeling

One of the three main components of the hydraulic modeling was to simulate the HGL of the Muddy River and Stony Brook Conduit for various design storms and physical scenarios. Table 2-2 provides a summary of peak HGL elevations at key locations in the Muddy River/Stony Brook system and Figures 2-1 through 2-7 show peak HGLs along the Muddy River, from the Charles River to Leverett Pond.

The frequency of the storm that causes flooding in the Stony Brook Conduit at Parker Street near Wentworth Institute was determined for both existing conditions and recommended improvements. For existing conditions, the data suggest that the HGL reaches street level on an annual basis. A storm with a return period of approximately 10 years can be expected to cause severe surcharging and possible street flooding at Parker Street with recommended improvements in place. The volume and duration of overflows as well as the predicted peak flood elevations at Parker Street for the various design storms are shown in Table 2-3.

8.2 Sediment Quantity

The major objective in this part of the analysis was to determine the amount of time it will take for sediment to re-accumulate to existing depths in the Muddy River. As shown in Table 5-1, with best management practices in place, sediment depths will not reach existing depths for 50 years or more with few exceptions.

8.3 Sediment Quality

Numerous factors will likely improve sediment quality in the future, such as the ban on the use of certain chemicals and leaded gasolines as well as specific programs like the Stony Brook Conduit cleaning and lining, the BWSC Catch Basin Identification and Cleaning Project, the Brookline Illegal Sanitary Connection Removal Program and the Management Plan for the Muddy River Restoration Project. A brief discussion on the concentrations of contaminants was also included in this report. With best management practices in place, the concentrations of contaminants such as metals, nutrients, and bacteria are expected to gradually decrease over time.

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Figure 2-6. Peak HGLs for the 100-yr Design Storm

Figure 2-7. Peak HGLs for the October 1996 Storm

Figure 2-8. Storm Frequency vs. Peak HGL, Stony Brook Conduit at Parker Street

Appendix A: Inflow Hydrographs

Appendix B: Outflow Hydrographs

Table 2-2

Peak HGL Elevations

	Design Storm								Calibration Storm	
	Sept 11, 1960		Oct 13, 1990		May 15, 1954		Aug 18, 1955		Oct 20, 1996	
	2-Year Storm		10-Year Storm		25-Year Storm		100-Year Storm			
Location	Existing Conditions	Recomm. Improv.	Existing Conditions	Recomm. Improv.	Existing Conditions	Recomm. Improv.	Existing Conditions	Recomm. Improv.	Existing Conditions	Recomm. Improv.
Muddy River										
Boston Gatehouse No.1	111.2	111.5	111.6	112.2	112.9	113.2	113.6	114.2	112.0	112.2
Upper Fens Pond	112.3	112.1	113.1	113.2	116.5	115.1	117.8	115.6	113.6	113.1
Riverway near Brookline Gatehouse	116.1	112.5	118.2	113.7	120.7	116.7	121.6	116.7	118.9	113.5
Muddy River Conduit										
At upstream end	113.8	112.1	115.2	113.2	117.2	117.2	117.4	117.1	115.9	113.1
Stony Brook Conduit										
Archdale	135.7	134.9	137.4	136.6	140.5	139.9	141.2	141.1	138.5	137.3
Parker St @ Wentworth Institute	119.0	115.7	119.7	117.2	120.7	118.3	120.9	119.1	120.2	116.7
Boston Gatehouse No.1	116.2	113.9	116.4	115.3	116.7	116.0	116.8	116.6	116.3	114.9

Elevations in reference to MDC Datum
Note: Sediment in Muddy River Conduit not removed for the Recommended Improvements.
More details on duration and volume of flooding at Parker Street provided in Table 2-3.

Table 2-2a

Peak HGL Elevations for Bank-to-Bank Dredging

	Design Storm								Calibration Storm	
	Sept 11, 1960		Oct 13, 1990		May 15, 1954		Aug 18, 1955			
	2-Year Storm		10-Year Storm		25-Year Storm		100-Year Storm		Oct 20, 1996	
Location	Bank-to-Bank	Difference in HGL (a)	Bank-to-Bank	Difference in HGL (a)	Bank-to-Bank	Difference in HGL (a)	Bank-to-Bank	Difference in HGL (a)	Bank-to-Bank	Difference in HGL (a)
Muddy River										
Boston Gatehouse No.1	111.5	0.0	112.2	0.0	113.2	0.0	114.2	0.0	112.2	0.0
Upper Fens Pond	112.1	0.0	113.2	0.0	115.1	0.0	115.6	0.0	113.1	0.0
Riverway near Brookline Gatehouse	112.5	0.0	113.7	0.0	116.7	0.0	116.7	0.0	113.5	0.0
Muddy River Conduit										
At upstream end	112.1	0.0	113.2	0.0	117.2	0.0	117.1	0.0	113.1	0.0
Stony Brook Conduit										
Archdale	134.9	0.0	136.6	0.0	139.9	0.0	141.1	0.0	137.3	0.1
Parker St @ Wentworth Institute	115.7	0.0	117.2	0.0	118.3	0.0	119.1	0.0	116.7	0.0
Boston Gatehouse No.1	113.9	0.0	115.3	0.0	116.0	-0.1	116.6	0.0	114.9	0.0

Elevations in reference to MDC Datum

(a) Bank-to Bank peak HGL minus peak HGL under recommended improvements.

Note: Sediment in Muddy River Conduit not removed.

Table 2-3

Overflow Volumes and Durations at Parker Street

Storm		Existing Conditions			Recommended Improvements		
		Peak HGL (MDC Datum)	Overflow Volume (ac-ft)	Street Flooding Duration (hours)	Peak HGL (MDC Datum)	Overflow Volume (ac-ft)	Street Flooding Duration (hours)
2-Year	Sept 11, 1960	119.0	31	7	115.6	0	0
10-Year	Oct 13, 1990	119.7	58	10	117.2	0	0
25-Year	May 15, 1954	120.7	100	13	118.3	10	4
100-Year	Aug 18, 1955	120.9	115	40 (31) (a)	119.1	33	8
Calibration	Oct 20, 1996	120.2	77	16	116.6	0	0

(a) Elapsed time from initial street flooding to end of street flooding is 41 hours.
Total time with HGL above street level is 31 hours.

Note: HGL indicates height at manhole, and is not believed to be as significant to flooding as overflow volume and duration

Table 7-1

Existing Concentrations of Contaminants

(all concentrations in ppm)

	Leverett Pond	The Riverway	Back Bay Fens
arsenic	< 60	< 60	< 35
cadmium	< 3	< 6	6.9 to 14.8
chromium	41.2 to 122	23.1 to 112	66.3 to 344
copper	203 - 240	85.7 to 448	389 to 710
lead	657 to 919	156 to 1100	979 to 1410
mercury	1.2 to 1.4	1 to 2.3	2.5 to 6.3
nickel	29.2 to 29.3	15.5 to 43.2	37.3 to 70.6
zinc	527 to 574	225 to 879	778 to 1070
COD	na	na	na
oils and grease	na	na	na
PAHs	0.077 to 26	0.08 to 30	0.1 to 11
BOD	na	na	na
total phosphorous	na	na	na
nitrates	na	na	na
TSS	na	na	na

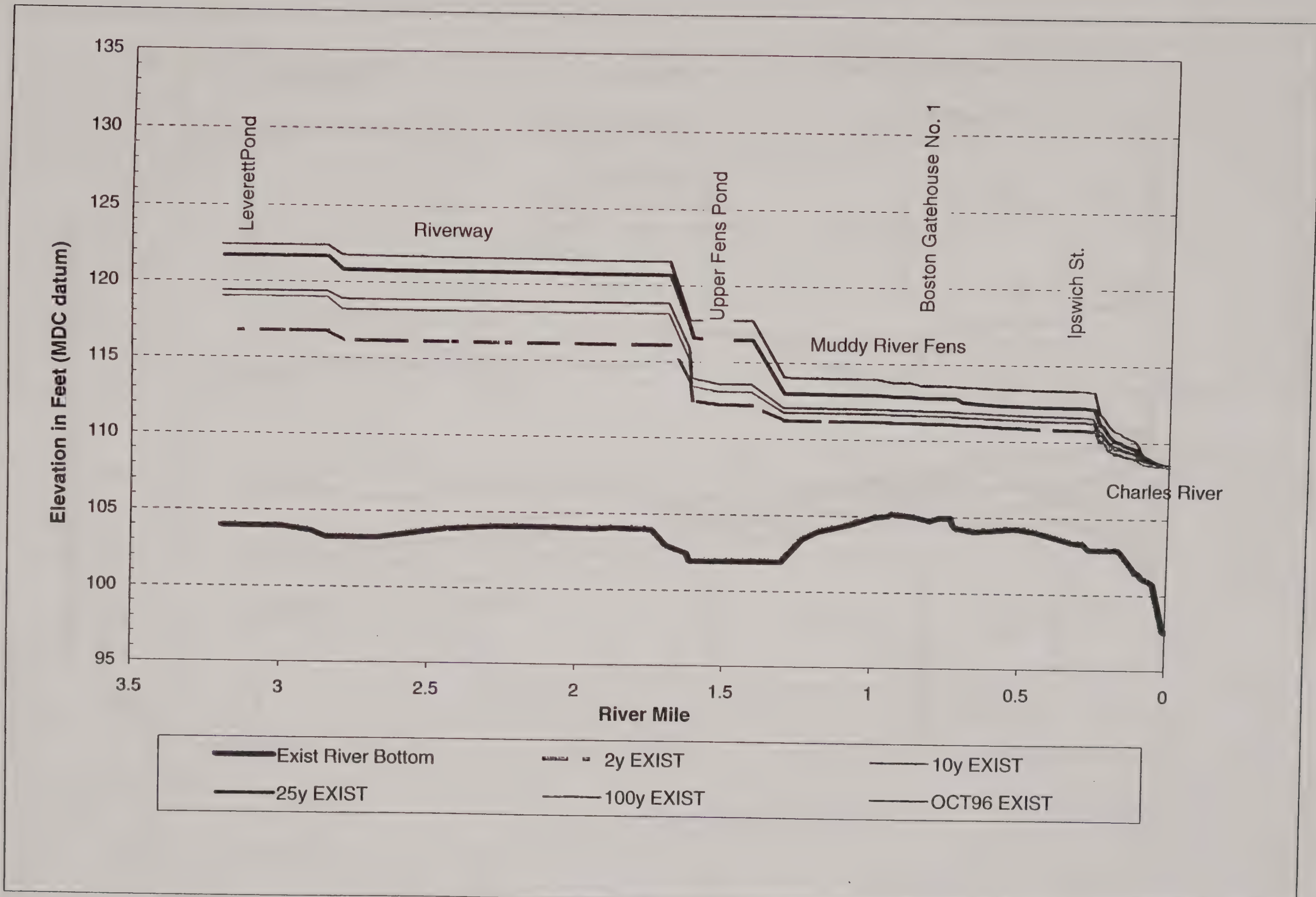


Figure 2-1
Peak HGLs for Various Storms
Existing Conditions

CDM Camp Dresser & McKee

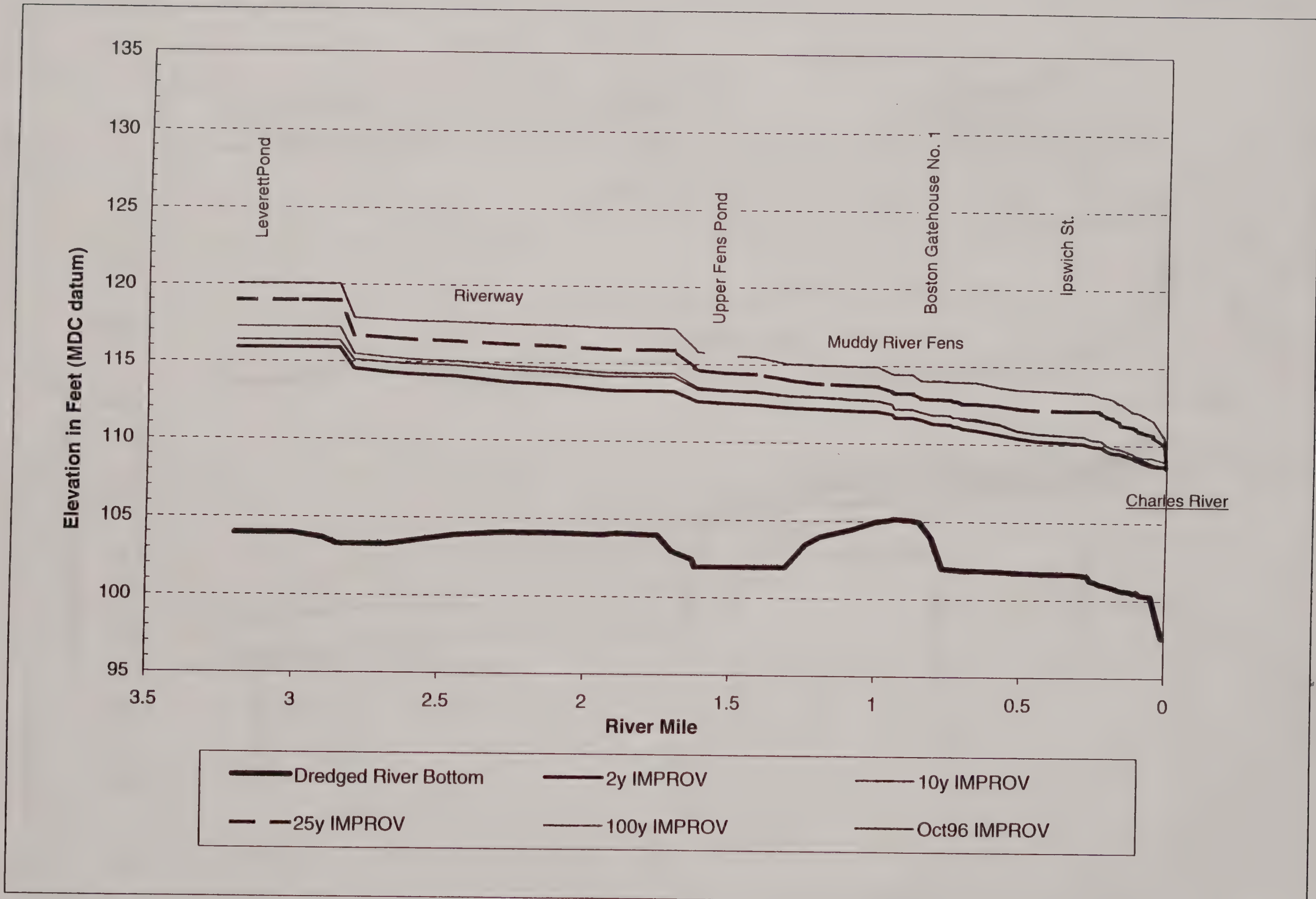


Figure 2-2
Peak HGLs for Various Storms
With Recommended Improvements

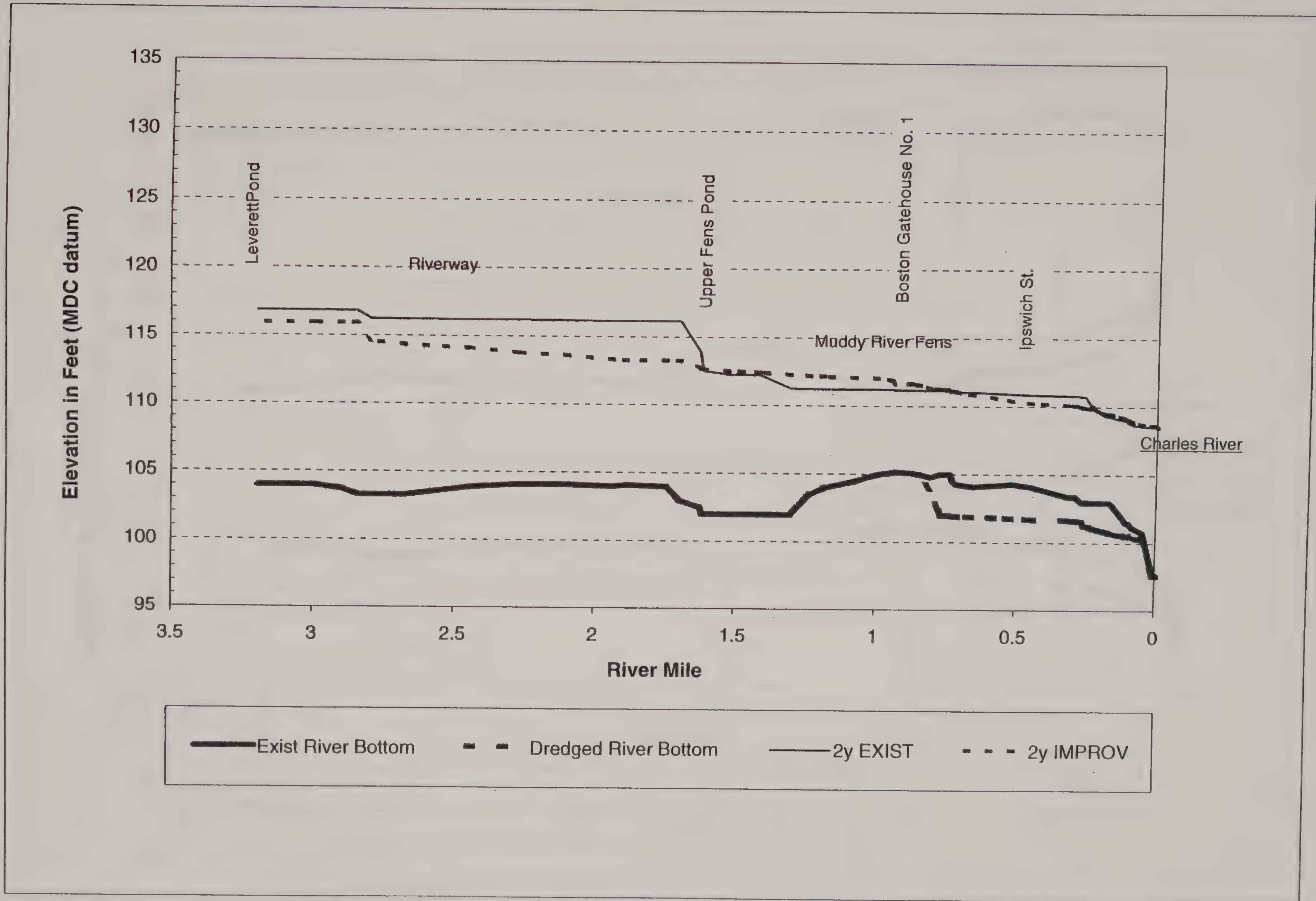


Figure 2-3
Peak HGLs for the 2-yr Design Storm

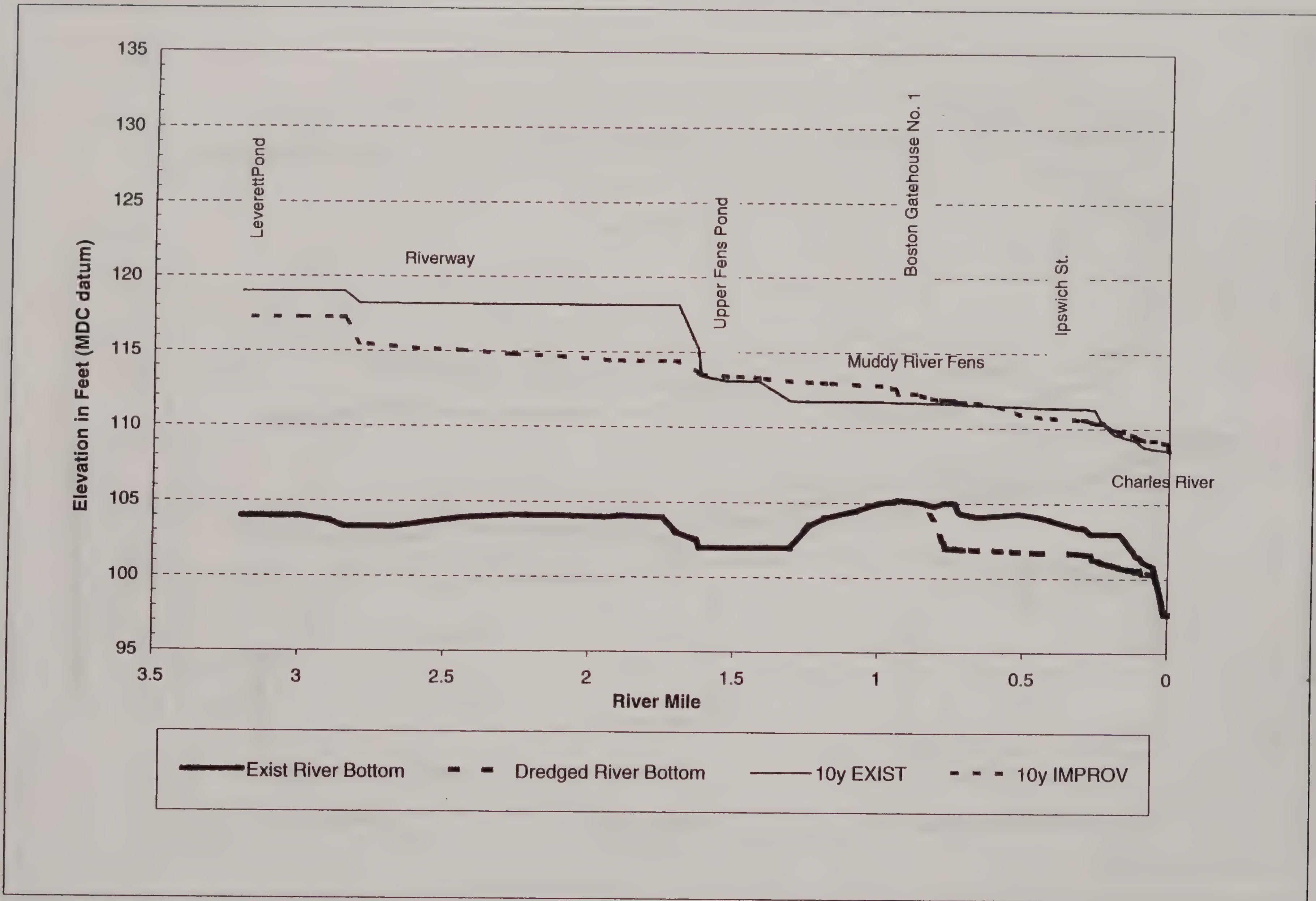


Figure 2-4
Peak HGLs for the 10-yr Design Storm

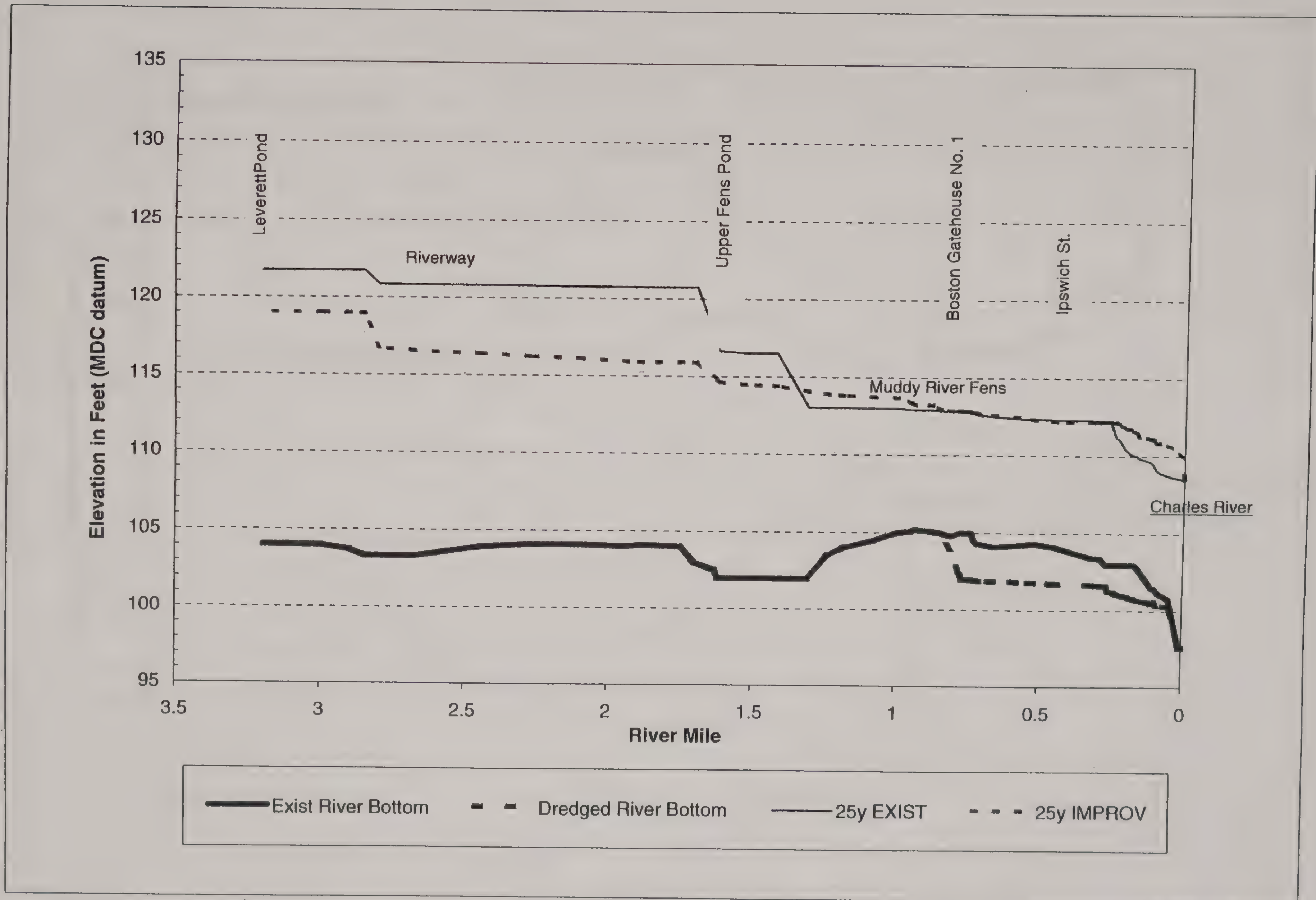


Figure 2-5
Peak HGLs for the 25-year Design Storm

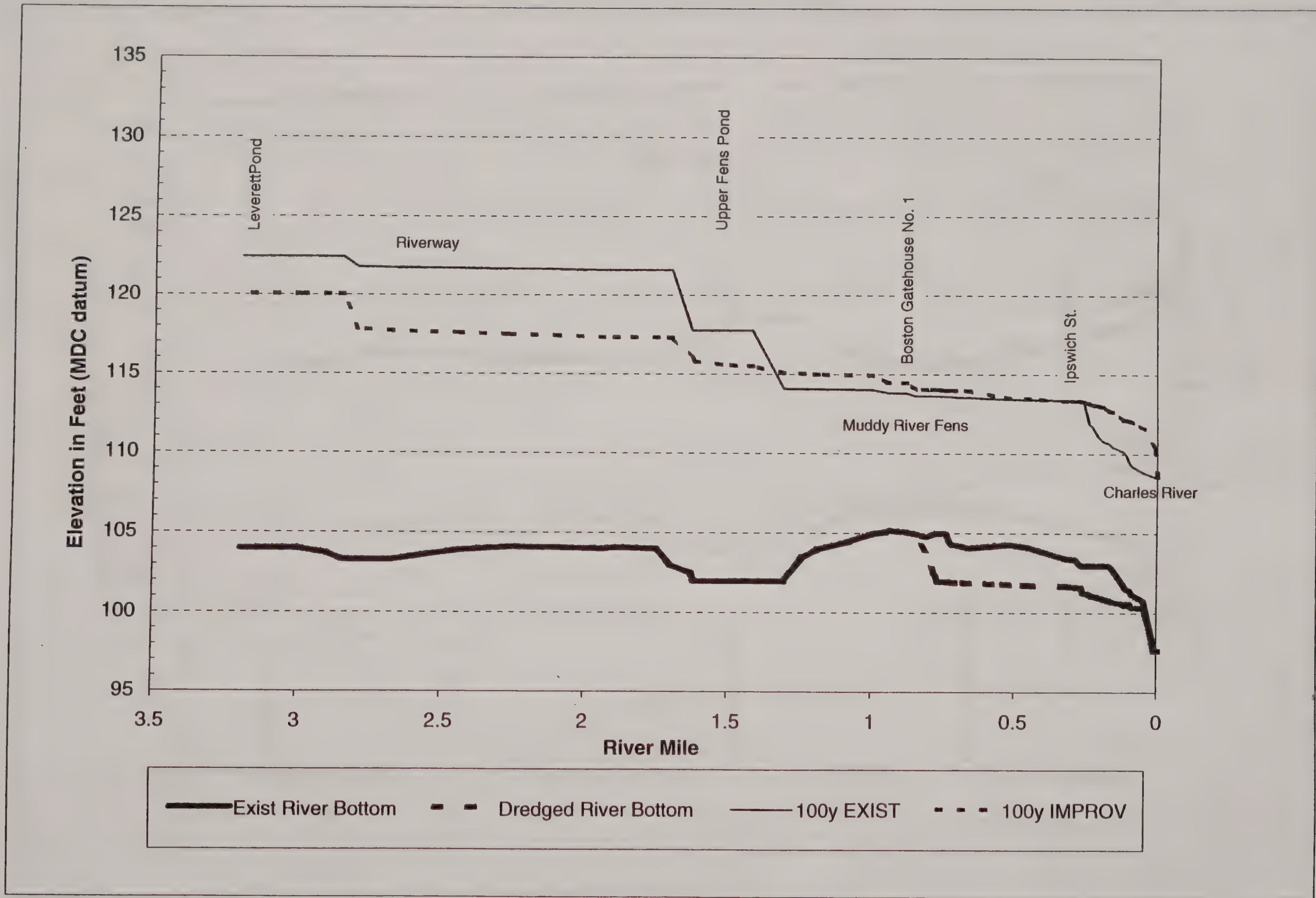


Figure 2-6
Peak HGLs for the 100-yr Design Storm

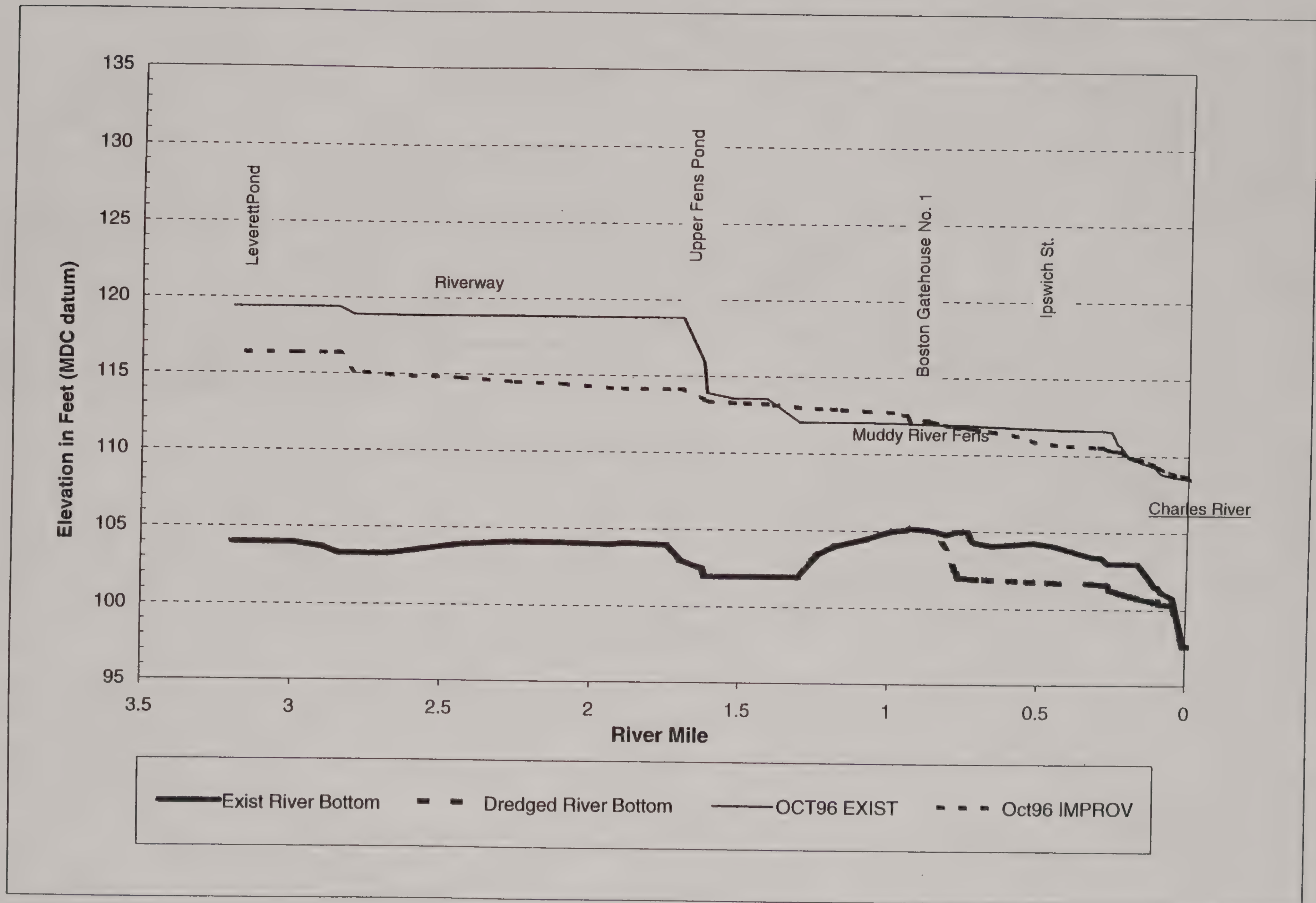


Figure 2-7
Peak HGLs for the Oct. 1996 Storm

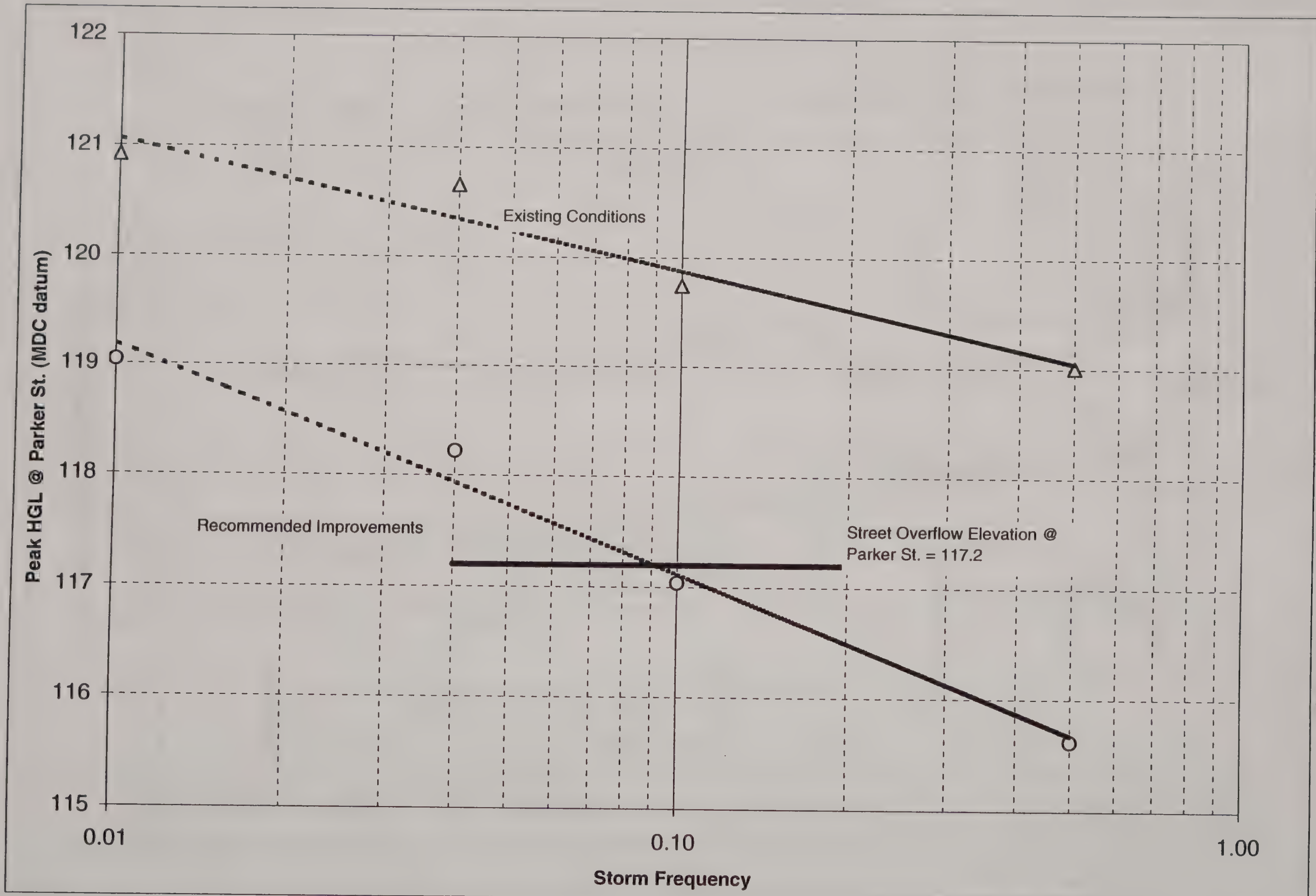
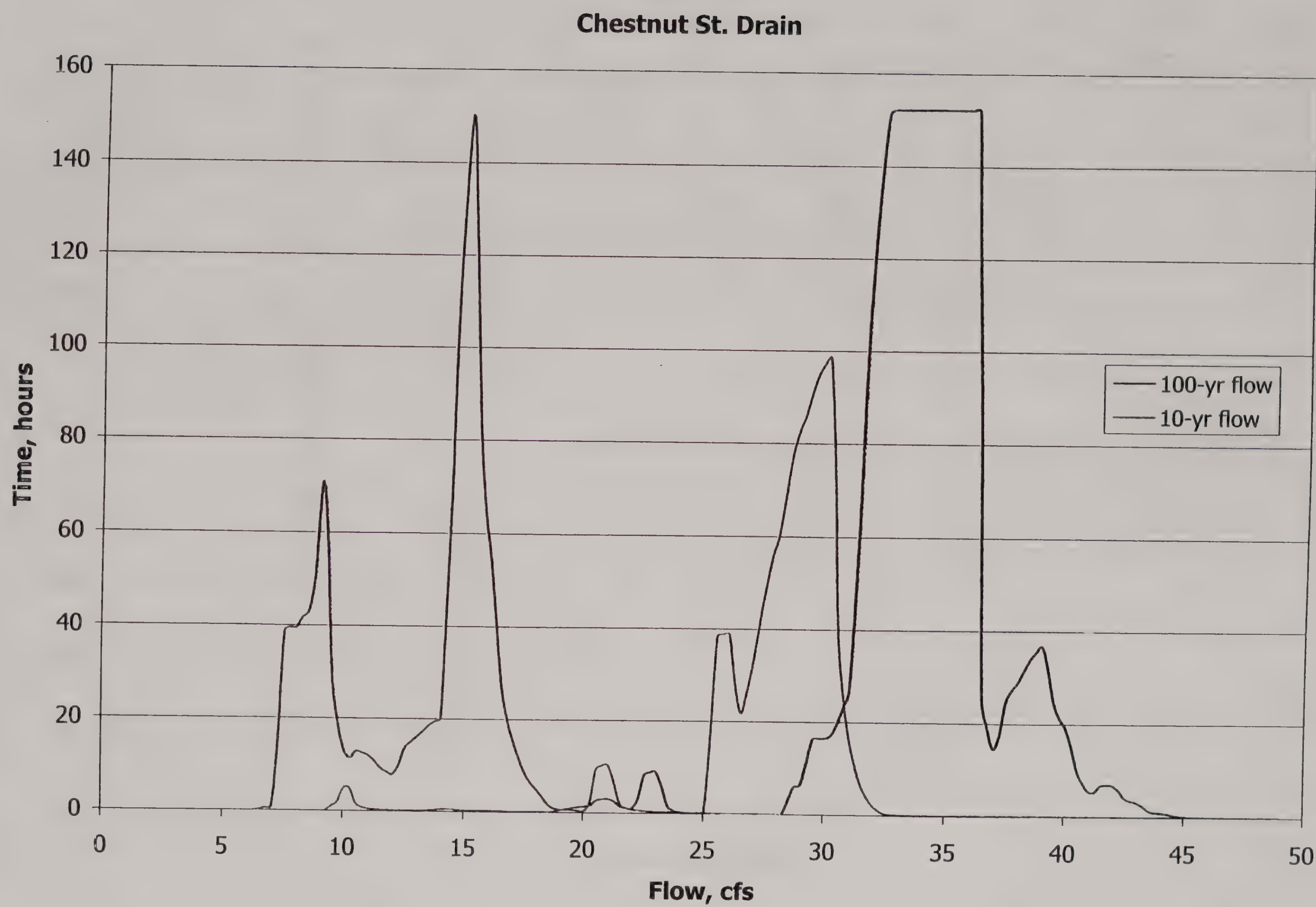
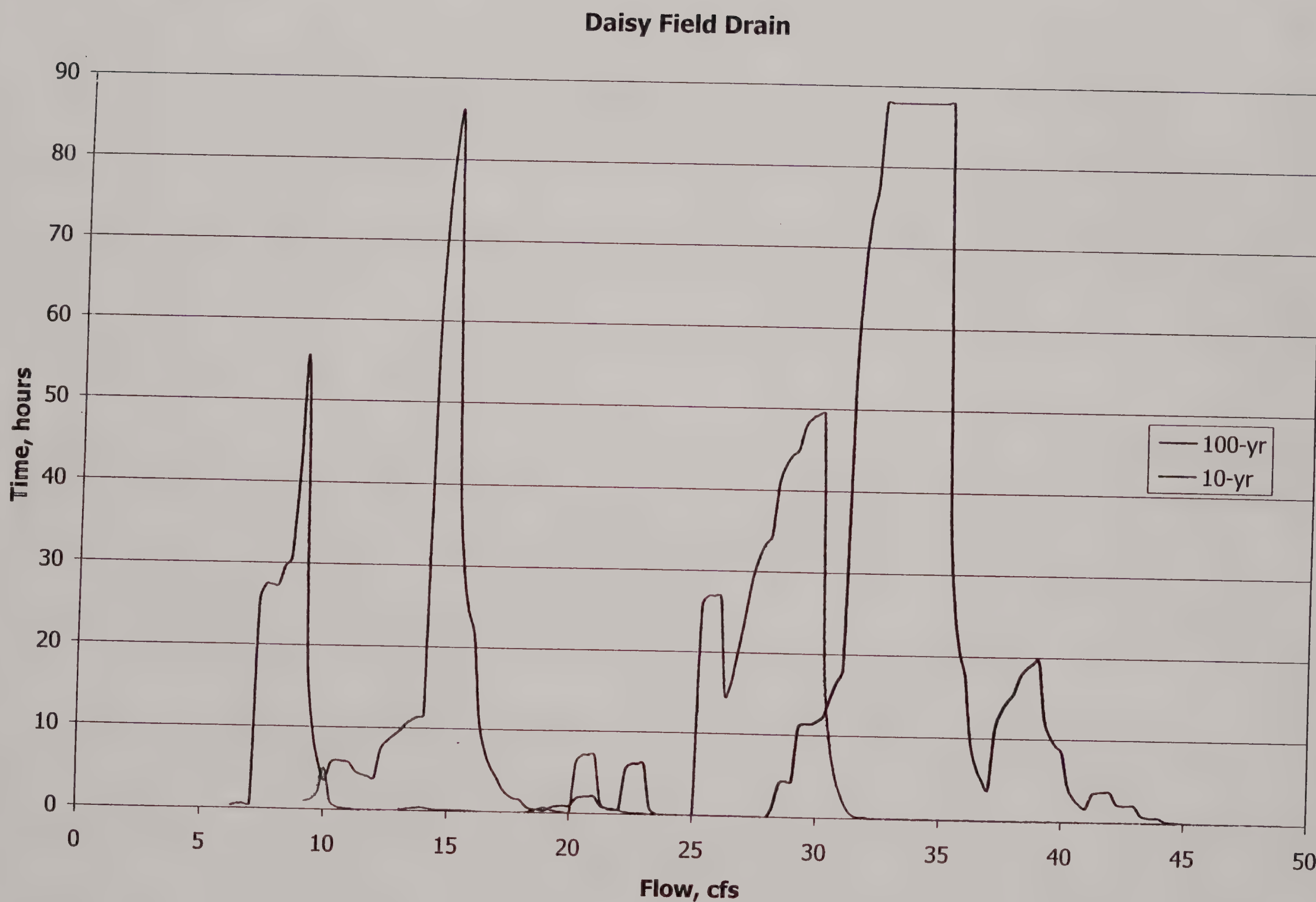


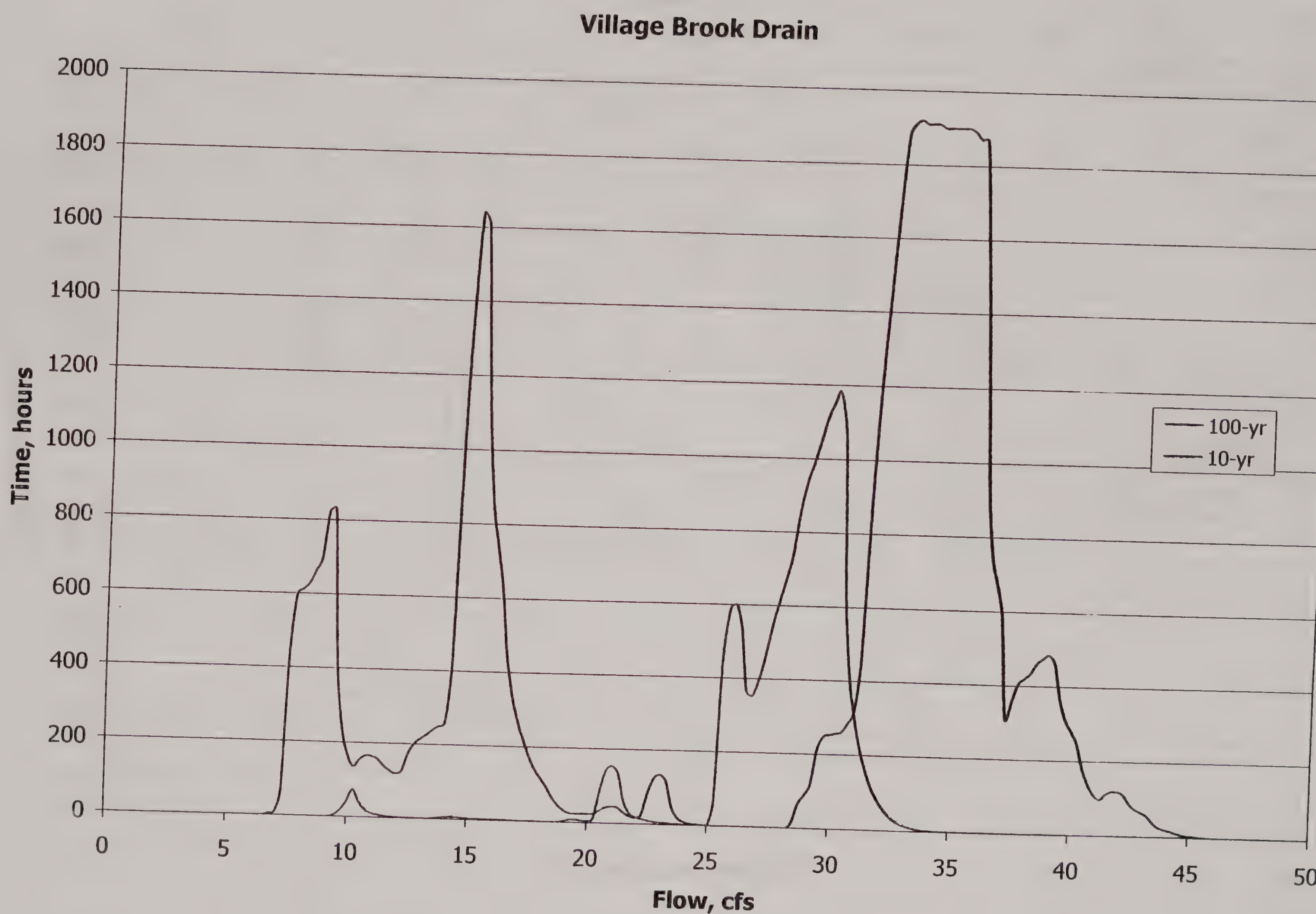
Figure 2-8
Storm Frequency vs. Peak HGL, Stony Brook Conduit at Parker St.

Appendix A

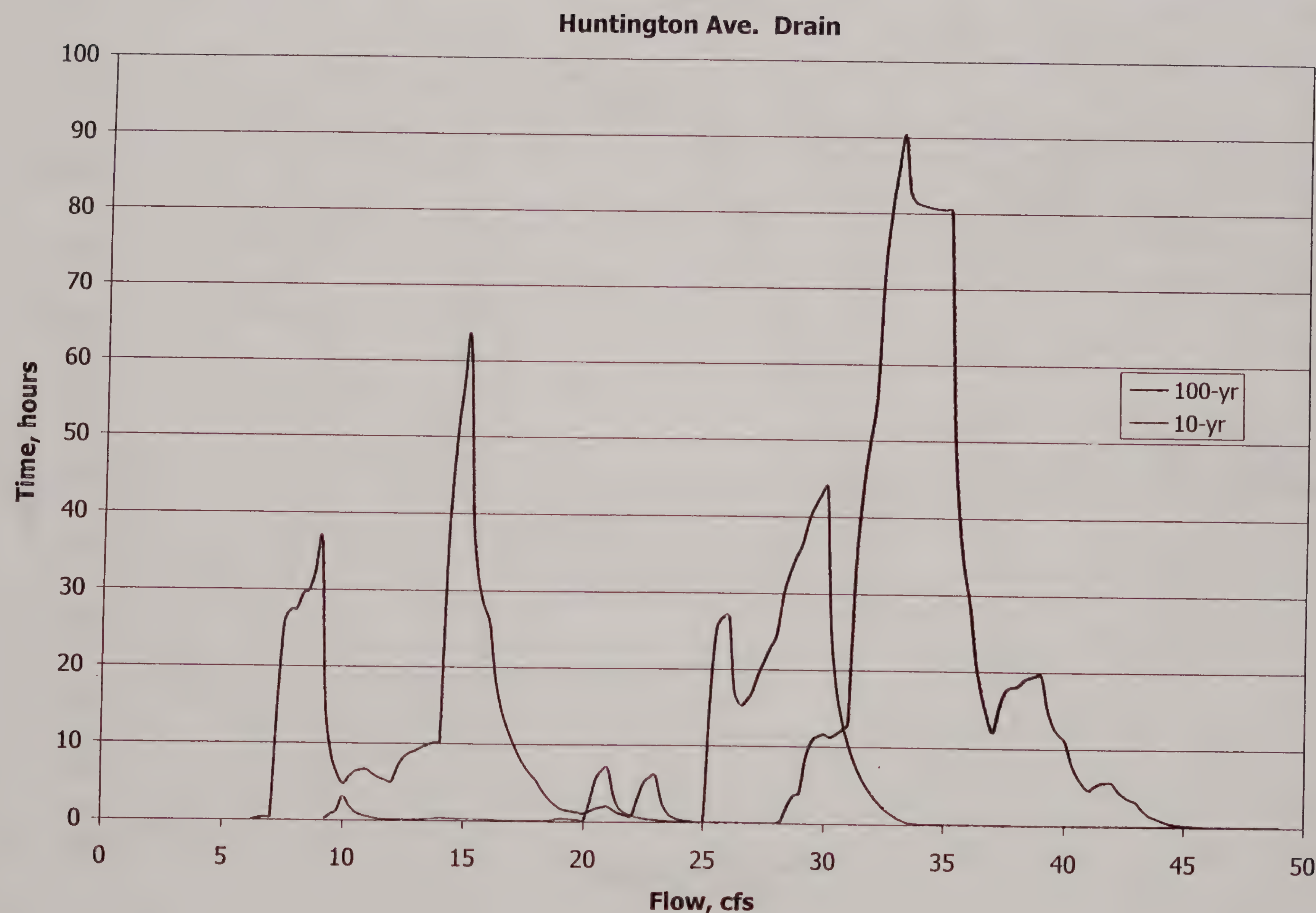
Inflow Hydrographs

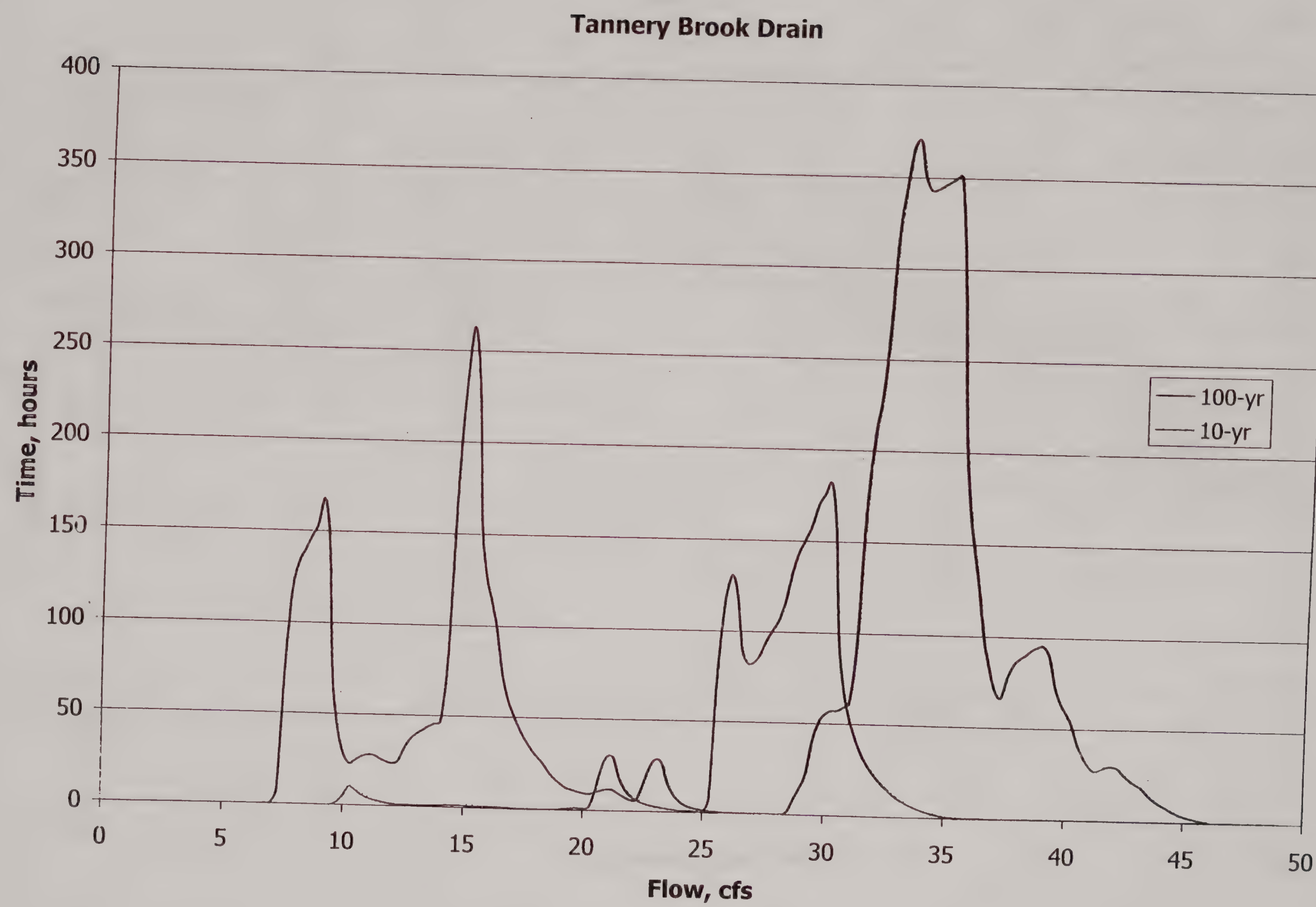

Chestnut St. Drain
160
140
120
100
80
60
40
20
0
Time, hours
0
5
10
15
20
25
30
35
40
45
50
Flow, cfs
100-yr flow
10-yr flow


Daisy Field Drain
Time, hours
Flow, cfs
100-yr
10-yr
0
10
20
30
40
50
60
70
80
90
0
5
10
15
20
25
30
35
40
45
50

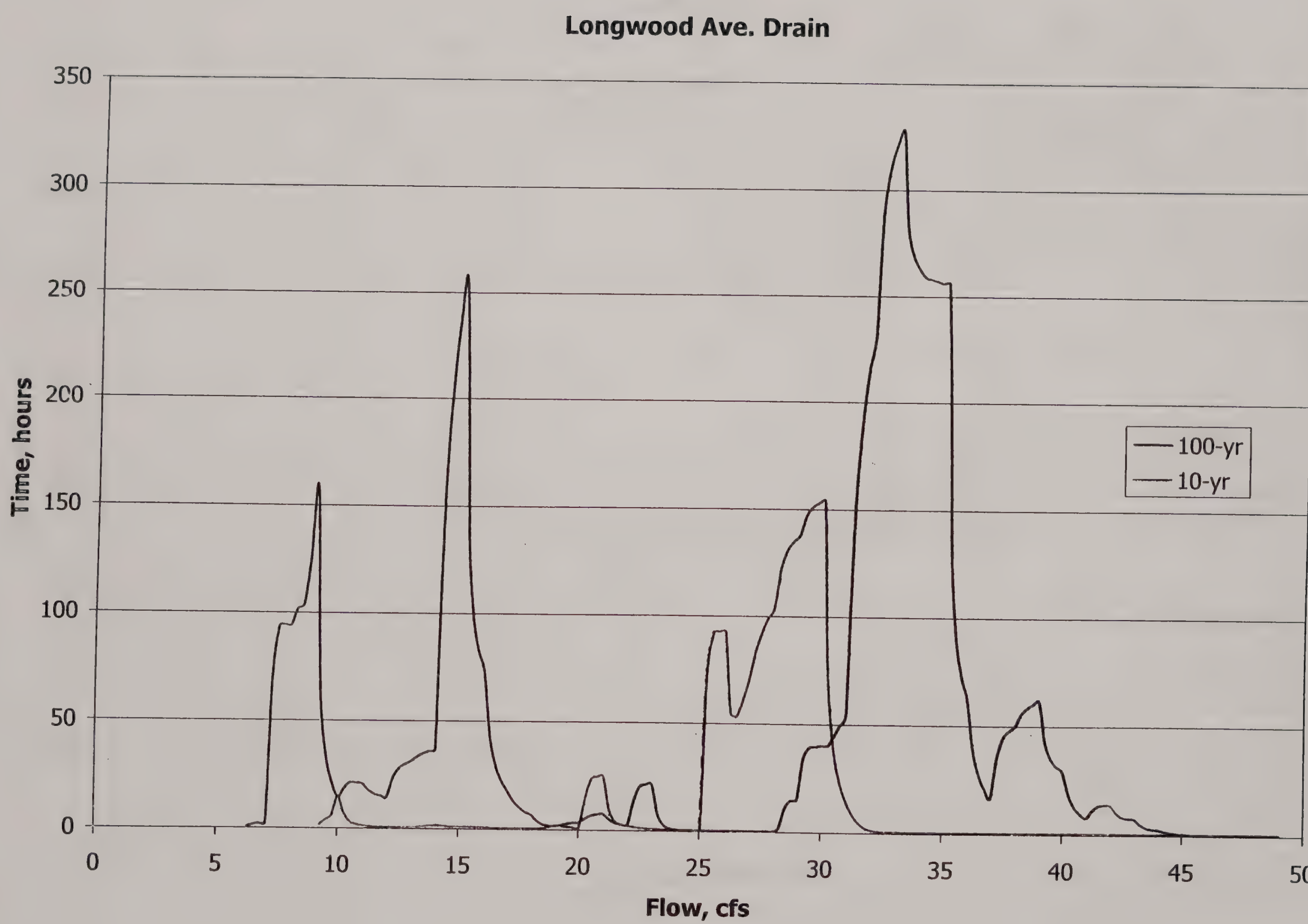


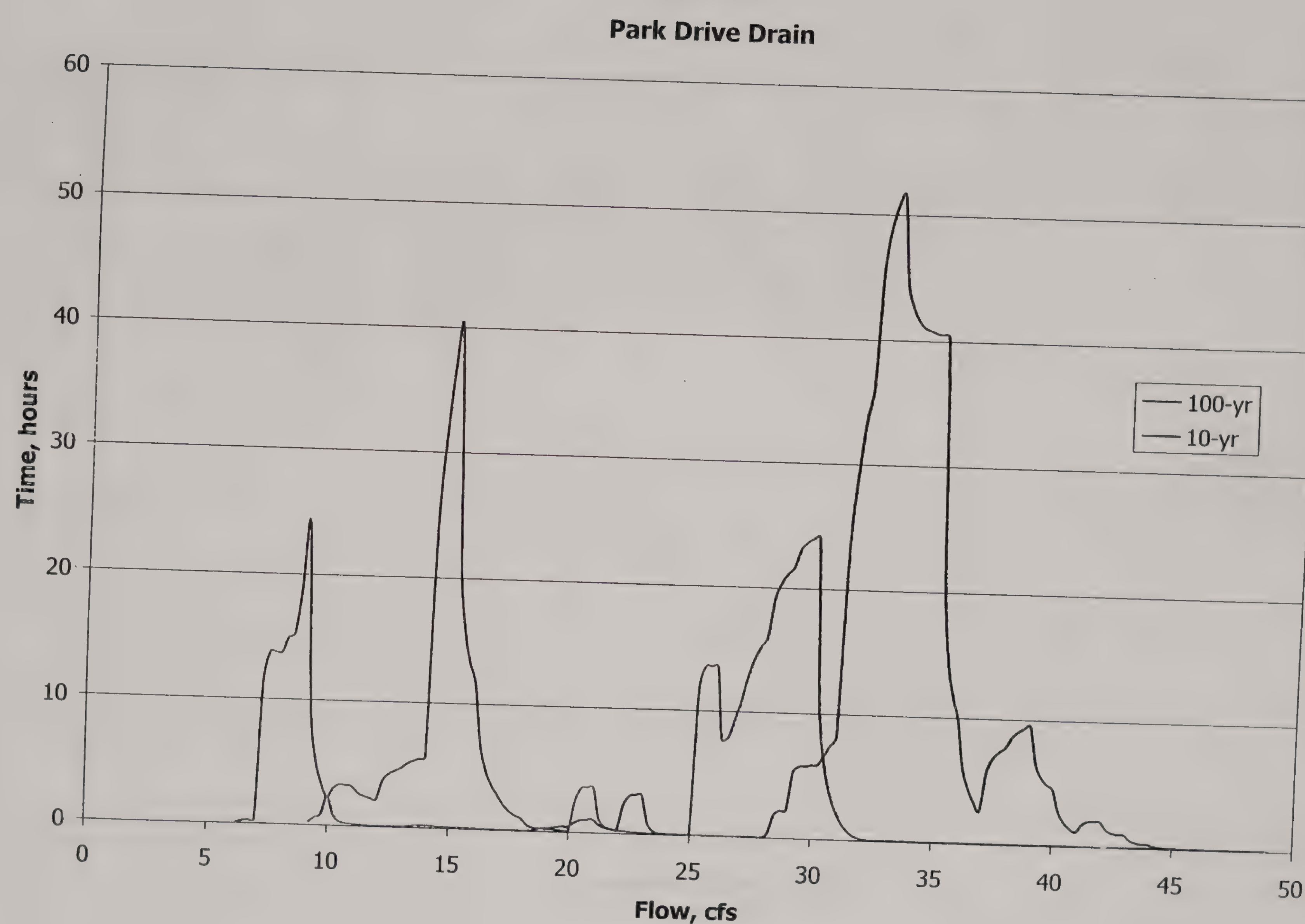
Village Brook Drain
Time, hours
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
5
10
15
20
25
30
35
40
45
50
Flow, cfs
100-yr
10-yr


Huntington Ave. Drain
Time, hours
Flow, cfs
100-yr
10-yr
0
10
20
30
40
50
60
70
80
90
100
0
5
10
15
20
25
30
35
40
45
50



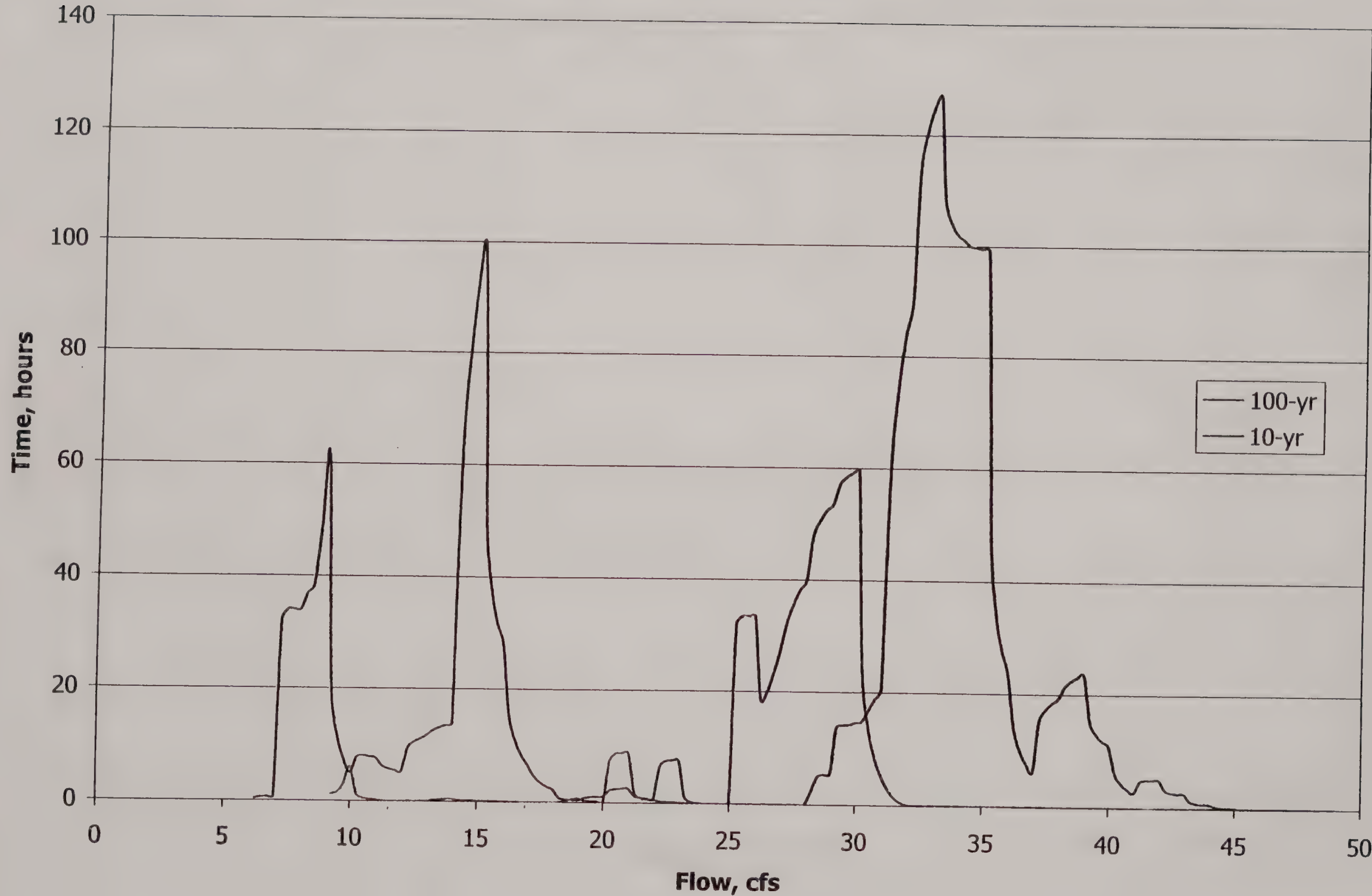
Tannery Brook Drain
400
350
300
250
200
150
100
50
0
Time, hours
0
5
10
15
20
25
30
35
40
45
50
Flow, cfs
100-yr
10-yr

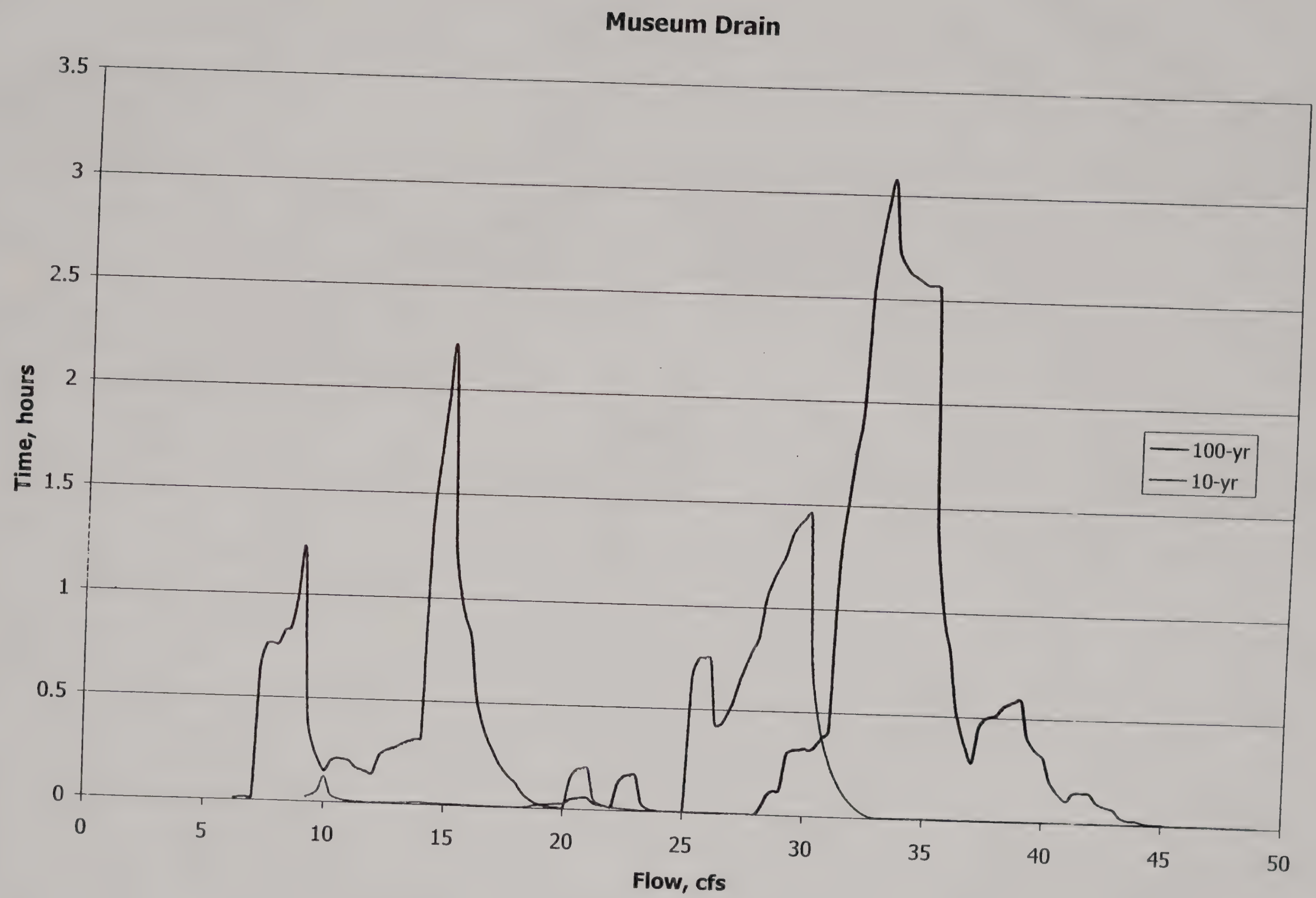

Longwood Ave. Drain
Time, hours
350
300
250
200
150
100
50
0
0
5
10
15
20
25
30
35
40
45
50
Flow, cfs
100-yr
10-yr



Park Drive Drain
Time, hours
Flow, cfs
100-yr
10-yr
0
10
20
30
40
50
60
0
5
10
15
20
25
30
35
40
45
50

Emmanuel College Drain

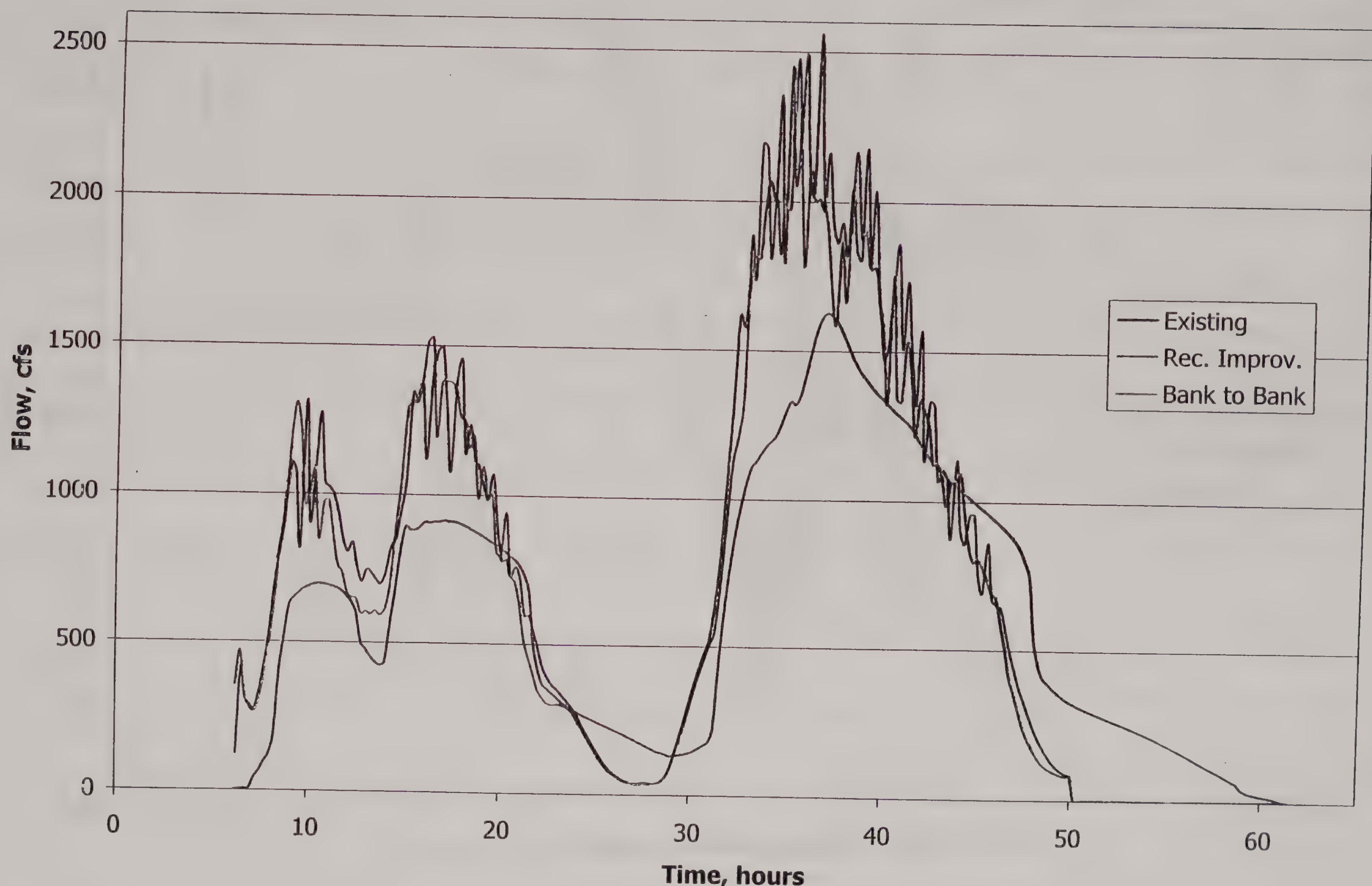



Museum Drain
Time, hours
3.5
3
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
30
35
40
45
50
Flow, cfs
100-yr
10-yr

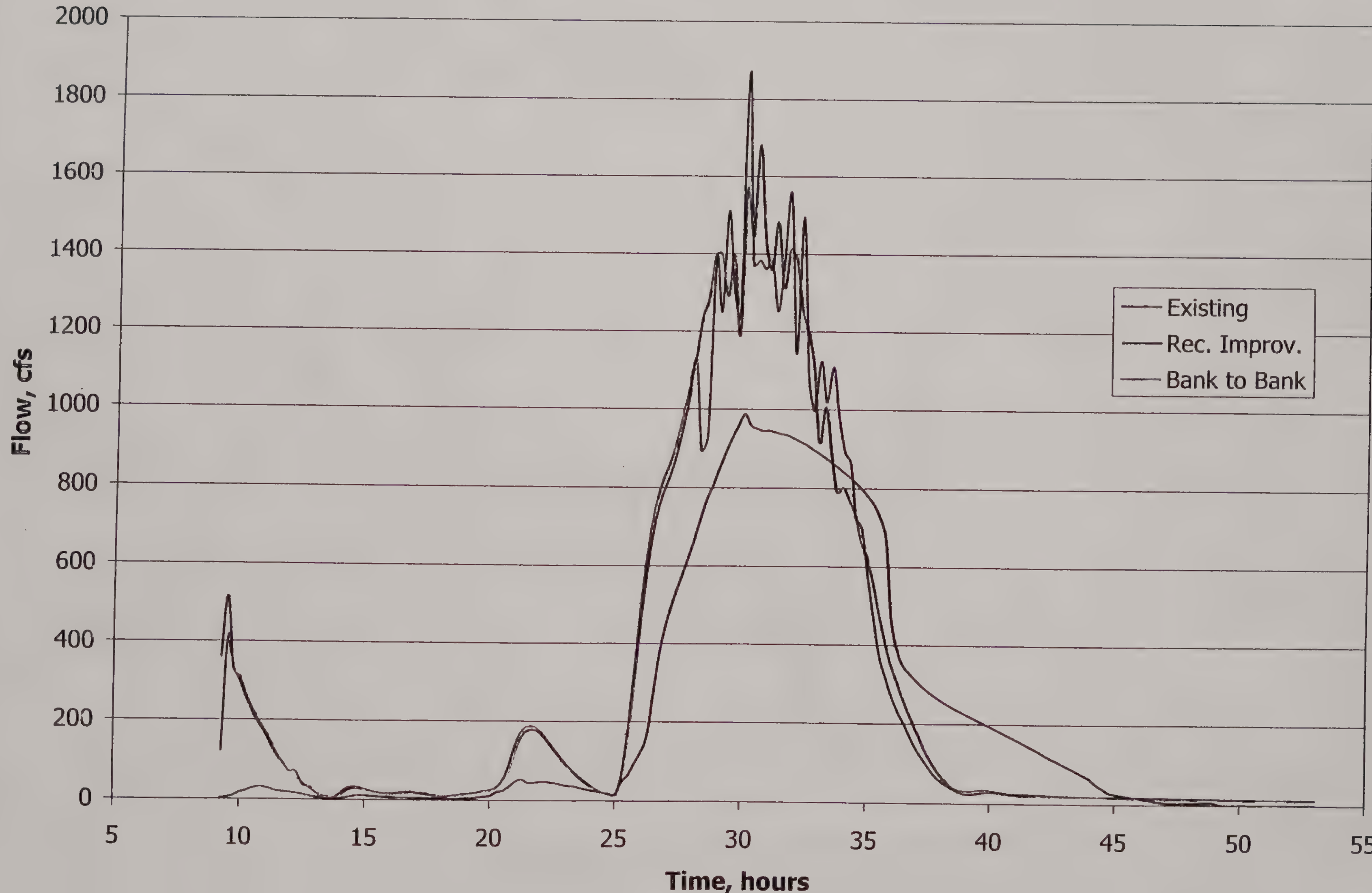
Appendix B

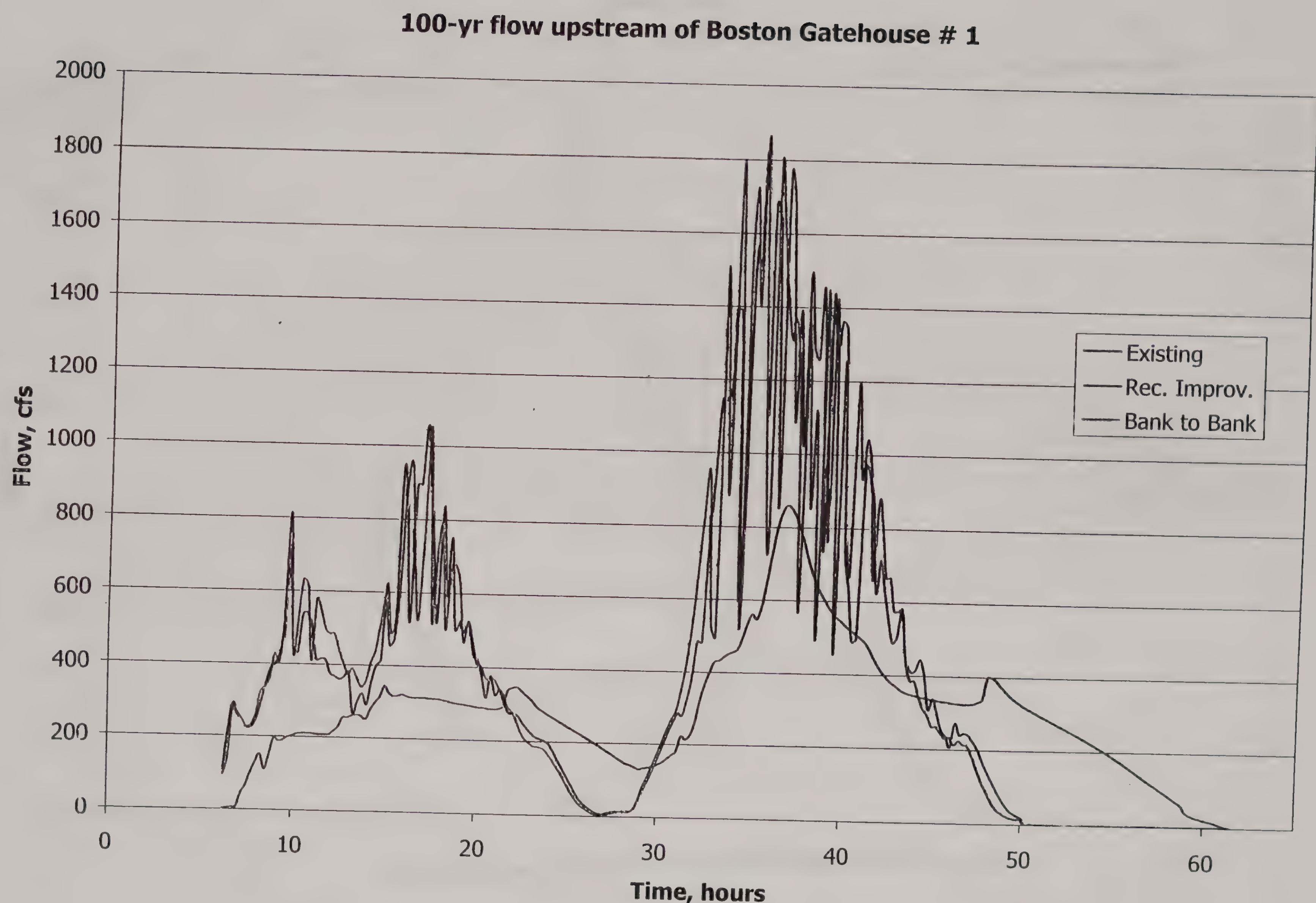
Outflow Hydrographs

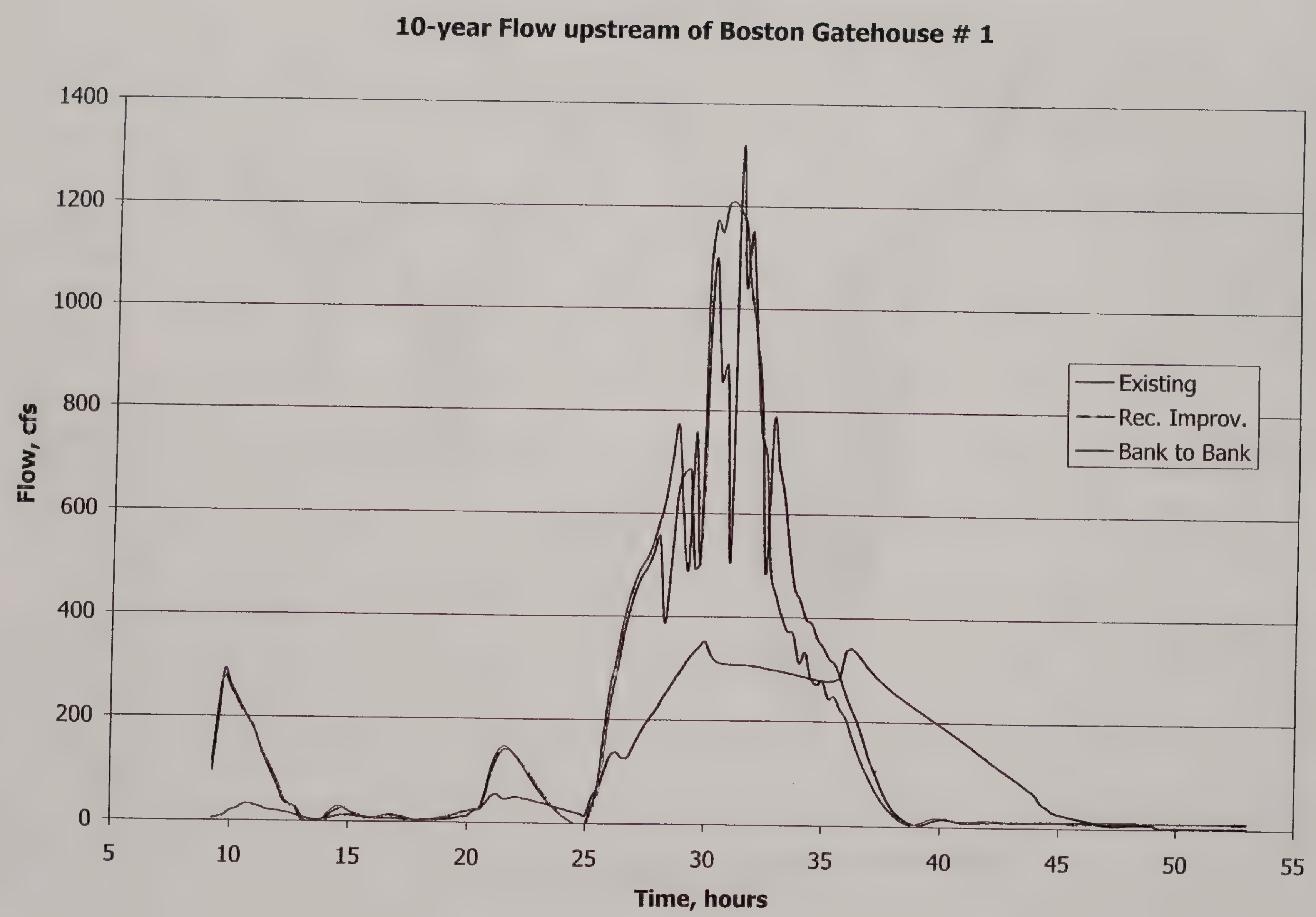
100-yr flow downstream of Boston Gatehouse # 1



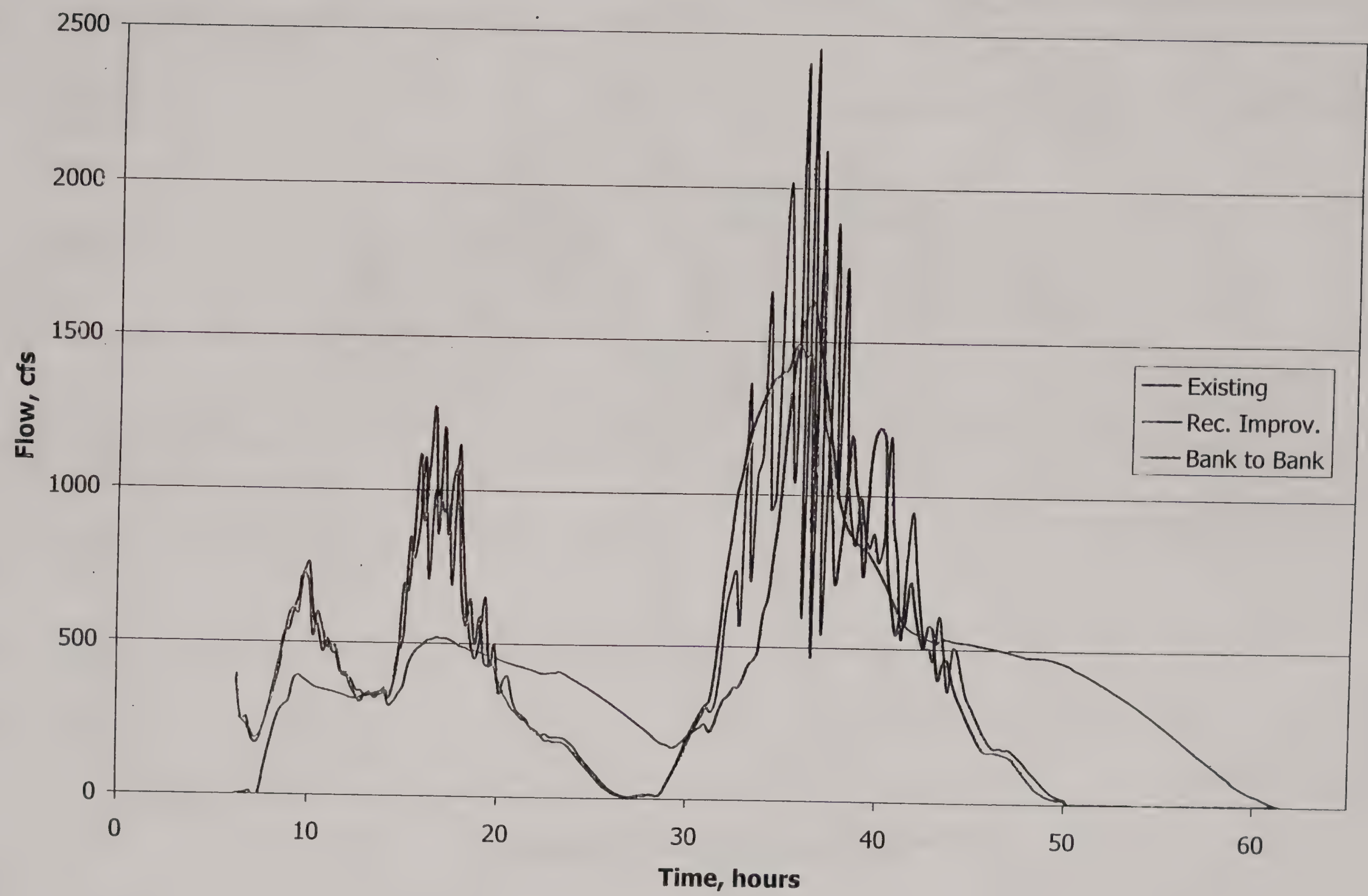
10-year Flow downstream of Boston Gatehouse # 1

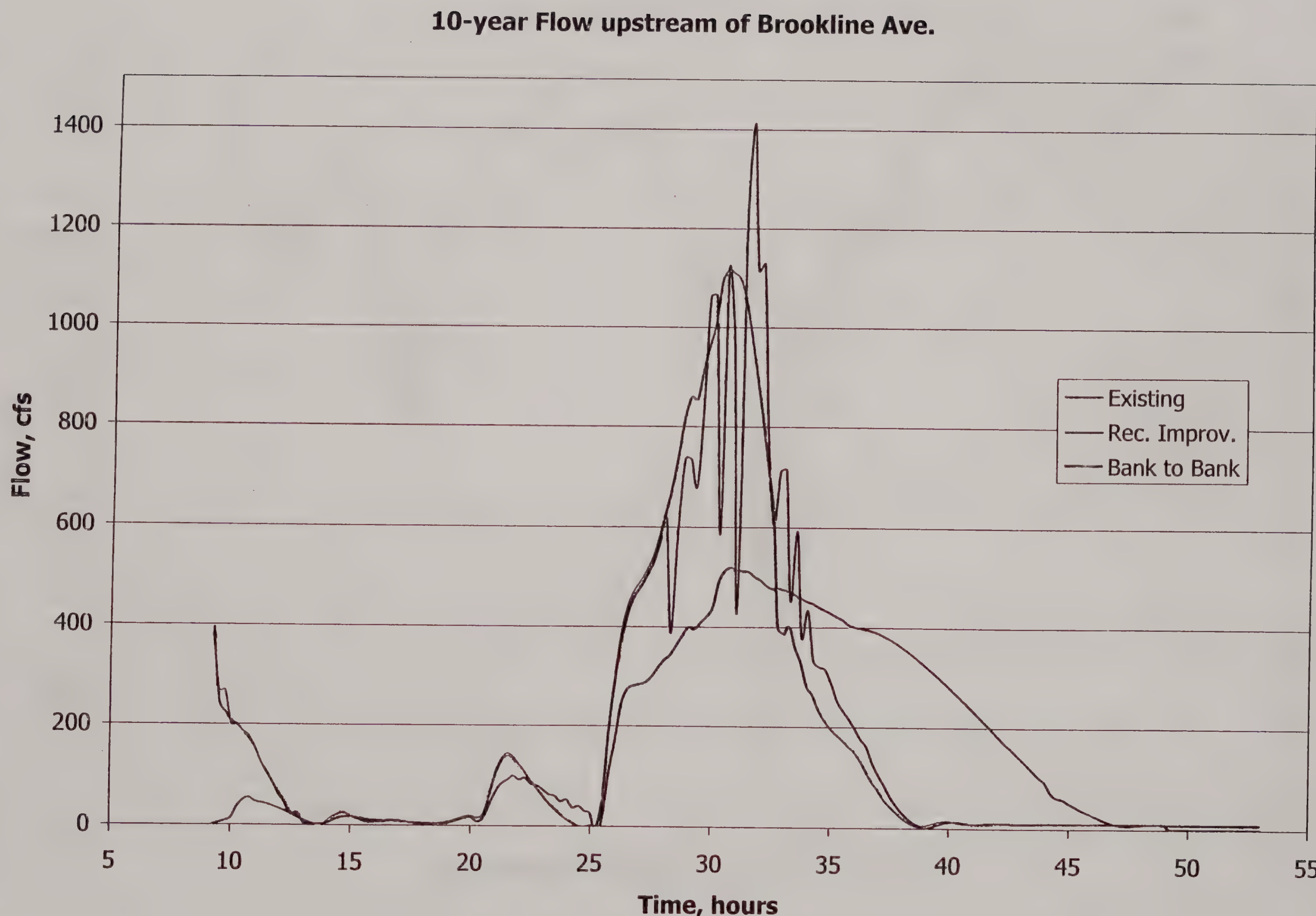



100-yr flow upstream of Boston Gatehouse # 1
Flow, cfs
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
10
20
30
40
50
60
Time, hours
Existing
Rec. Improv.
Bank to Bank

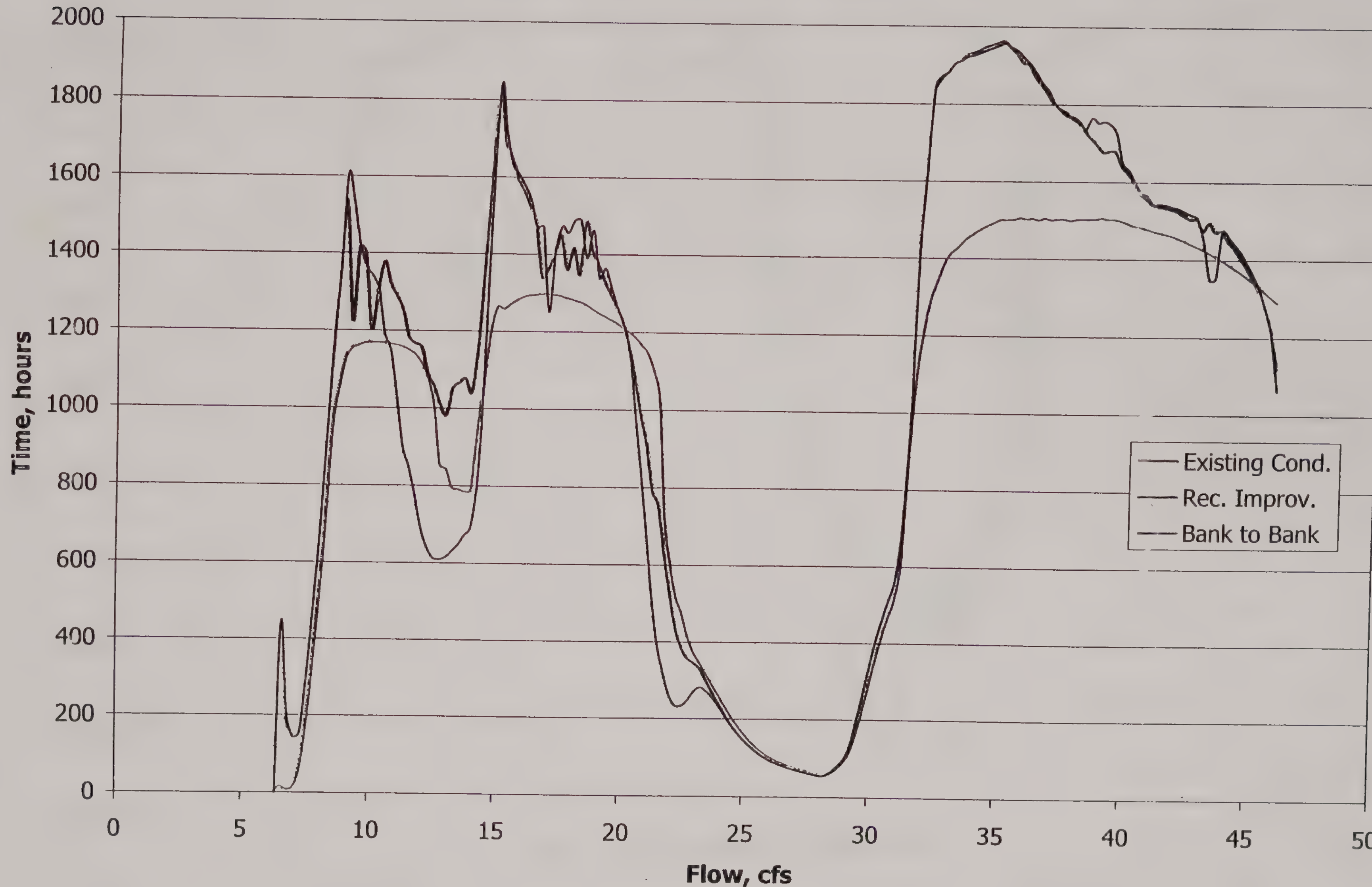

10-year Flow upstream of Boston Gatehouse # 1
Flow, cfs
1400
1200
1000
800
600
400
200
0
5
10
15
20
25
30
35
40
45
50
55
Time, hours
Existing
Rec. Improv.
Bank to Bank

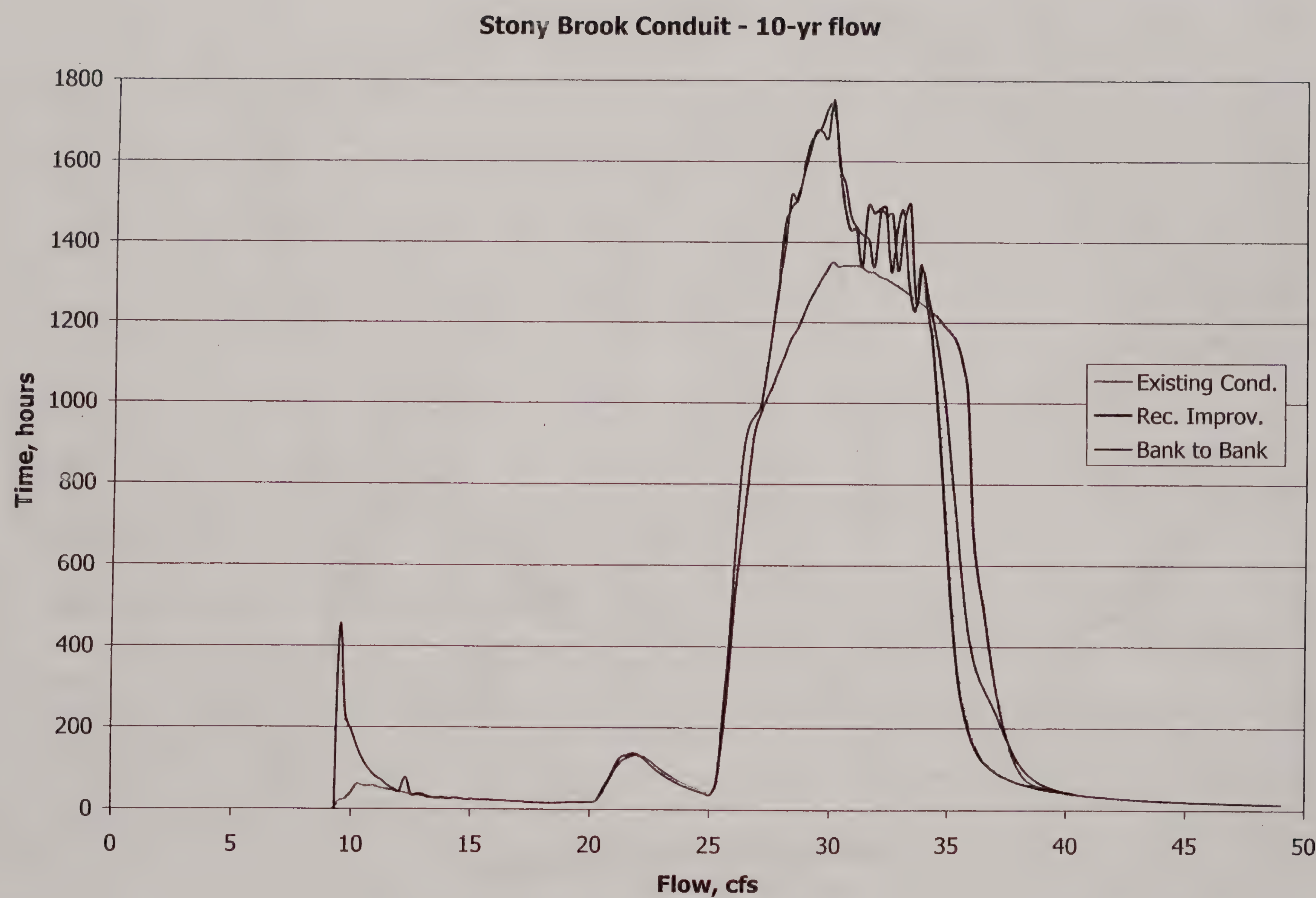
100-year flow upstream of Brookline Ave.




10-year Flow upstream of Brookline Ave.
Flow, cfs
1400
1200
1000
800
600
400
200
0
5
10
15
20
25
30
35
40
45
50
55
Time, hours
Existing
Rec. Improv.
Bank to Bank

Stony Brook Conduit - 100-yr flow




Stony Brook Conduit - 10-yr flow
1800
1600
1400
1200
1000
800
600
400
200
0
Time, hours
0
5
10
15
20
25
30
35
40
45
50
Flow, cfs
Existing Cond.
Rec. Improv.
Bank to Bank

CDM

consulting • engineering • construction • operations